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# Final Report

## COATING SYSTEM STUDIES FOR THE CORROSION PROTECTION OF HY 130 STEEL

Contract No.

N00600-69-C-0618

HYSTU Plan No. 303

Prepared by: D. W. Martin

D. D. Miller

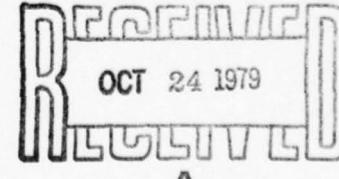
W. L. Engstrom

June 1974

The Boeing Aerospace Company  
Naval Systems Division  
Seattle, Washington 98124

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Annapolis Laboratory  
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## FOREWORD

This report covers the work performed under HYSTU Plan No. 303, Contract N00600-69-C-0618, "Coating System Studies for the Corrosion Protection of HY 130 Steel". The contract work period was from September 1973 to June 1974. The work was performed for the Annapolis Laboratory, Naval Ship Research and Development Center with Mr. J. J. Kelly as Technical Monitor. The contractor's report number is D180-18126-1.

## ACKNOWLEDGEMENTS

The authors wish to acknowledge the significant contributions to the program made by Messrs. M. H. Kiehle, H. A. Johnson, P. S. Jacobsen, G. Johanknecht, R. Underhill, D. Muretta, and C. Unger of The Boeing Company.

## ABSTRACT

The objectives of this program were to study the effects of aluminum and zinc metal substrates with a passive overcoat on the corrosion fatigue life of HY130 in a marine environment and to develop a shipboard repair process for hydrofoil strut and foil external coatings. Conclusions were reached about the effectiveness of the active metal substrates in protecting HY130. A repair material and procedure were recommended.

## KEY WORDS

Aluminum Metallizing	Organic Coatings
Zinc Metallizing	Epoxy Adhesives
Fatigue Life	Fatigue Testing
Corrosion Protection	

## 1.0 INTRODUCTION

The HY series steels require corrosion protection when exposed to a marine environment. Two coating systems that can be used for such protection are passive and active (galvanic) systems. Research at The Boeing Company has shown that a combination of an active substrate and a passive overcoat is the most promising candidate protection system for external hydrofoil strut and foil surfaces.

The program performed for this contract contained two tasks: 1) define the corrosion protection performance of active metallic substrates, and 2) develop repair techniques for two candidate coating systems.

## 2.0 SUMMARY AND CONCLUSIONS

This program was conducted under contract from the Department of Navy, Naval Ship Research and Development Center, Bethesda, Maryland to study the effects of an active metal substrate and passive overcoat on the corrosion fatigue life of HY 130 steel alloy and to develop repair techniques for two coating systems.

To define the performance of an active metal substrate for the corrosion protection of HY 130 in a marine environment, tests were conducted to determine the required thickness of metallizing and the extent of damage the metallizing could sustain and still protect the steel from corrosion. A limited amount of data was also generated to compare aluminum and zinc as metallizing materials. Fatigue test specimens were prepared and exposed to flowing sea water and then fatigue tested in a salt water environment. Results of the test led to the conclusion that all combinations of substrate material, substrate thickness and damage width tested provided improvement in the corrosion fatigue strength of HY 130 in sea water.

The following conclusions were made with respect to the metallic substrate test variables:

- o With the exception of the .005" aluminum substrate, all of the substrate material/gage combinations tested provided significantly improved corrosion fatigue strength; the .005" aluminum substrate provided a smaller improvement.
- o Prior exposure had no apparent influence on the corrosion fatigue life protection provided by the coating system.
- o The zinc substrate provided better protection than the aluminum substrate; however, as applied on the test specimens, it exhibited excessive delamination.
- o Damage widths studied (1/4", 1/2" and 1") had no apparent influence on the protection provided by the coating system.

- o The Laminar X-500 coating blistered over both the zinc and aluminum metallizing. The blistering was more extensive over the aluminum. Several other coatings (PR 1654, Hughson M-312, and Glidden Glid-flake) tested at the same time under company funded research exhibited little or no blistering.

The second task of this program was to develop two ship board coating repair techniques, one that would be suitable for use in emergency conditions, (repairs that could be accomplished in a 1 hour period), and a backup type repair that could be accomplished in 12 hours and would have a service life of up to 6 weeks. Two coating systems were chosen as being representative of systems that would be encountered in service. Repair materials such as epoxy coatings and adhesives, polyester coatings, and polyurethane coatings were tested for suitable cure cycles, ease of application and erosion resistance when applied to the representative coatings.

Results of the tests lead to the conclusion that an epoxy adhesive Hysol EA 960F was the best repair material for both coatings tested, Laminar X-500 and PR 1654, and for both types of repair. The following recommendations were also made:

- o When using EA 960F in a one-hour emergency repair, a minimum cure cycle of 30 minutes at 180 - 200°F is recommended.
- o The minimum cure cycle for EA 960F used for a 12 hour repair should be 8 hours at 70°F or above.
- o The repair area should be abrasively cleaned to obtain a bright metal surface and faired coating edge. A final cleaning with a solvent such as acetone or methyl-ethyl-ketone is recommended to remove all loose particles and contamination.

These recommendations involve procedures that can be accomplished under normal shipboard operating conditions. Appendices 1 and 2 detail the procedures for repair of the two coating systems.

### 3.0 PROGRAM TASKS

#### 3.1 Metallic Substrate Evaluation

##### 3.1.1 Background

HY130 steel and other low alloy steels require corrosion protection when exposed to a marine environment. Two of the systems that can be used for such protection are passive coating systems and active (galvanic) coating systems.

Results of Boeing Aerospace Company research (1)\* have shown that a combination of an active substrate and a passive overcoat appears to be the best approach to provide adequate, reliable protection of low alloy steels in a hydrofoil salt water environment. The Boeing tests of Reference 1 were corrosion fatigue tests conducted on 0.10" thick HY130 specimens which had been coated with a 0.010" thick layer of wire metallized aluminum. These tests were run with and without passive overcoats. Some tests were run with two "damaged" areas (1/4" wide circumferential strips without the aluminum). The results of these tests, Figure 1 showed that the aluminum substrate acted as a sacrificial anode and protected the steel such that the corrosion fatigue life of the protected specimens in sea water was equivalent to unprotected specimens in air. The coating concept was designed to protect the steel from erosion and also to provide short term corrosion protection in case of damage to the passive overcoat.

Since the above tests did not investigate the variables of sea water exposure prior to test, alternate metallic substrates, different substrate thicknesses, and different damage widths, this program was prepared to study the effects of these variables.

##### 3.1.2 Test Objectives

The main objectives of Task I were to determine the following:

- 1) The thickness of aluminum required to protect HY130 for selected time periods.
- 2) The extent of "damage" the aluminum coating can sustain and still retain the fatigue life of HY130 in air when tested in sea water.

\*Numbers in brackets refer to references at the end of the report.

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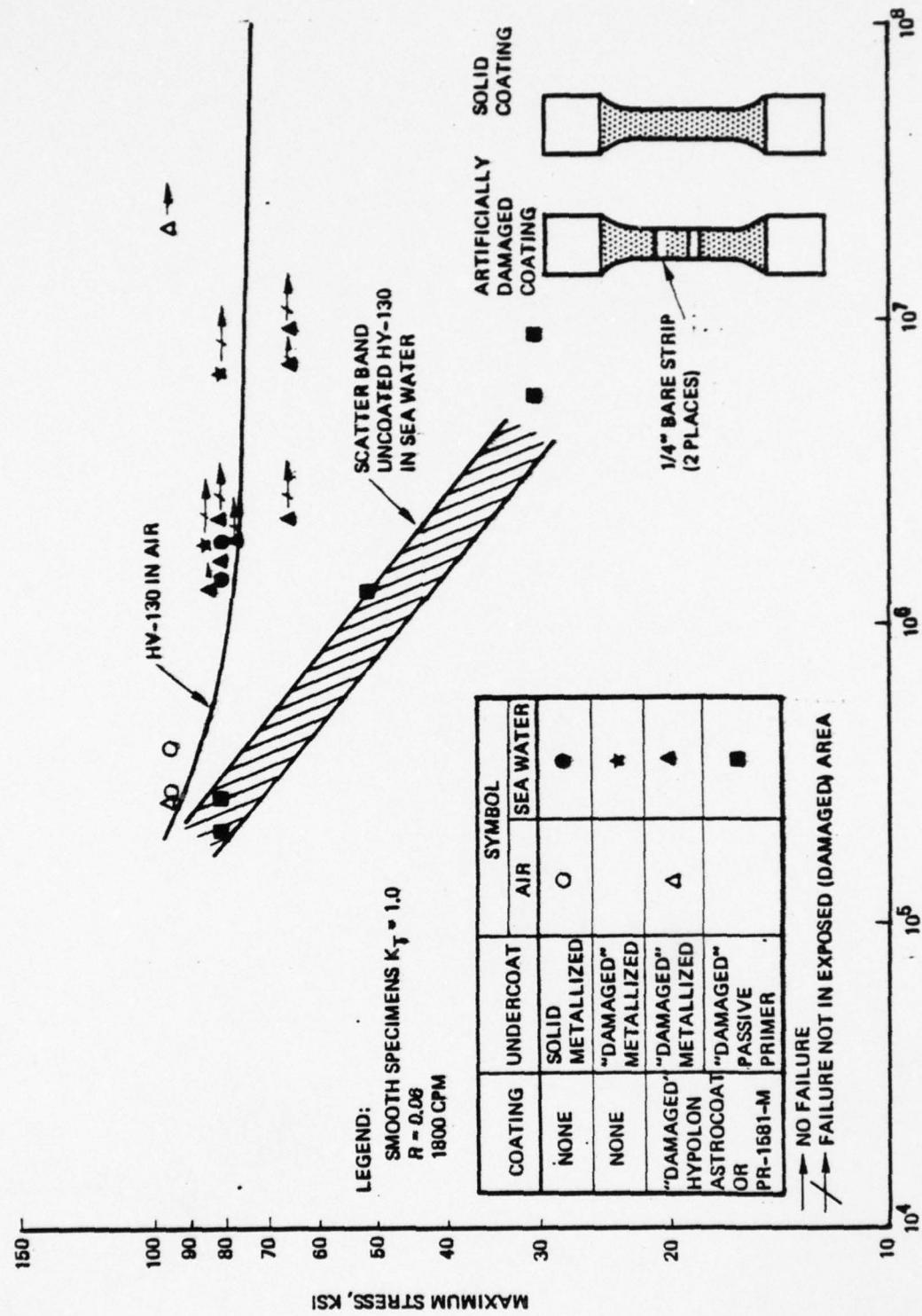


Figure 1: COATED HY-130 STEEL FATIGUE TEST RESULTS (REF. 1)

3) Comparable data to 1) and 2) for a limited number of zinc-coated specimens.

### 3.1.3 Test Material

The HY130 material used in this investigation came from the same heat as used in the Reference 1 tests. Mechanical properties are listed in Table I. The main chemical constituents, determined at The Boeing Company are shown in Table II.

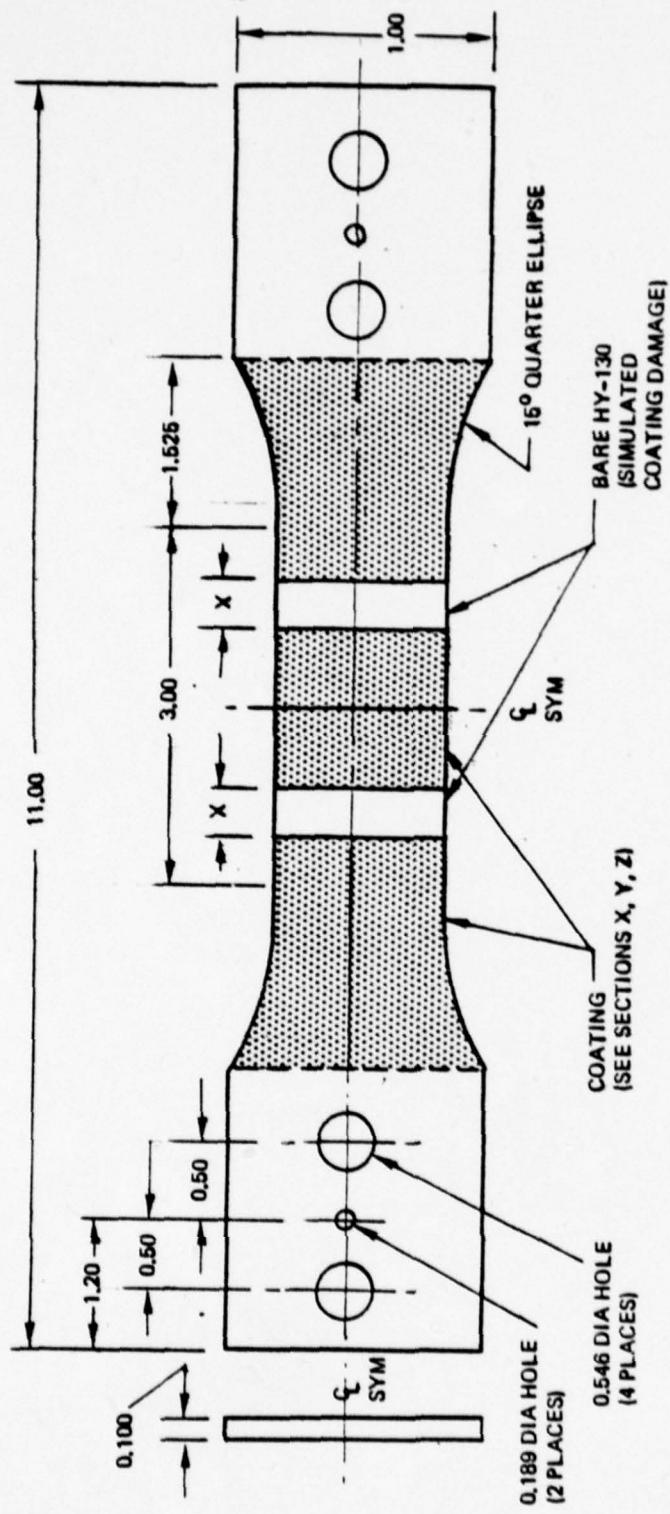
### 3.1.4 Test Procedures

#### 3.1.4.1 Fabrication of Test Specimens

The specimens were fabricated from the 3/16" thick HY130 sheet described above. They were milled to a thickness of 0.100 inch and to the smooth,  $K_f = 1$ , configuration shown in Figure 2. The rolling direction of the material was parallel to the long axis of the specimen. A 30 micro-inch RMS or better surface finish was achieved on all specimens. After deburring, the specimens were dye penetrant inspected per Boeing specification BAC 5423, sensitivity category B. Hand rework was done as required. The grip areas of each specimen were then grit blasted with steel or silicon carbide, Mesh 36-50, per Boeing specification BAC 5748 to prevent slippage in the test machines.

#### 3.1.4.2 Wire Metallizing (See APPENDIX III for Additional Process Details)

Specimen substrates were first prepared for coating by vapor degreasing and then grit blasting with Metelite F aluminum oxide abrasive. Areas which were not to be coated were next masked off with heat resistant tape. Wire metallized aluminum and zinc coatings were applied with Metco 8E flame spray equipment. All coatings were manually applied at a gun-to-work distance of six to ten inches and a traverse rate of approximately  $16 \pm 6$  inches per minute. Spray parameters for both coating types<sup>(1)</sup> were as follows:



1 Damaged area produced by masking the base metal during the aluminum metallizing and overcoating. Maskant is stripped after coating to expose base metal to test environment.

$K_t = 1.00$

Figure 2: "DAMAGED" FATIGUE SPECIMEN

Table I: MECHANICAL PROPERTIES OF 3/16" AS RECEIVED HY130 MATERIAL

GRAIN DIRECTION	ULTIMATE STRENGTH (KSI)	YIELD STRENGTH (KSI)	ELONGATION IN 2 INCHES (%)	REDUCTION IN AREA (%)
LONGITUDINAL	150.5	144.0	14	57
TRANSVERSE	150.7	142.0	14	53

Table II: CHEMICAL COMPOSITION OF 3/16" AS RECEIVED HY 130 MATERIAL  
(% AS DETERMINED BY BOEING TESTS)

NICKEL	5.00
CHROMIUM	0.38
MOLYBDENUM	0.49
VANADIUM	0.058

	Air	Oxygen	Acetylene	Wire Speed
Lighting Pressure*	55 psi	28 psi	15 psi	---
Gas Flow at Operating Conditions	51 (2)	44 (2)	40 (2)	90 ± 15 in/min.

- (1) Pure Aluminum (99.0%) 1/8 inch diameter (MIL-W-6712B)  
 Pure Zinc (99.9%) 1/8 inch diameter (MIL-W-6712B)

- (2) Metco Flow Meter Readings - Cubic feet/hour

\*Lighting Pressure - This is the line pressure at the time of torch ignition.  
 Under actual operating conditions at the gas flow rate listed, the  
 pressure may be reduced.

Spraying was done in such a manner that the coating was applied uniformly with a progressive build-up over the surface of specimen. Forced air cooling was used to maintain specimen temperatures below 350°F during the coating operation.

Thicknesses were controlled by measuring test specimens with a micrometer.

#### 3.1.4.3 Passive Overcoating

The Laminar X-500 coating system was applied using a DeVilbiss Type MBC siphon spray gun with a No. 30 tip and the following application sequence:

1. Phos-Pho-Neal Primer (31-6-6) to a dry film thickness of 0.3 to 0.5 mil. Dried 1/2 hour or until dry to touch.
2. Cross coats of Epoxy Primer (1-1Y015) to a dry film thickness of 0.75 to 1.25 mil. Dried a minimum of 12 hours.
3. Applied cross coats of Orange Uremet Enamel (1-10-19) to a dry film thickness of 2 to 2.5 mil. Dried 2-8 hours.
4. Applied cross coats of Yellow Uremet Enamel (1-1Y-36) to a dry film thickness of 2 to 2.5 mil.
5. Total coating dried a minimum of 7 days prior to use.

#### 3.1.4.4 Coating Variables

Each specimen was masked with two strips, 1/4", 1/2", or 1" wide before the coatings were applied as shown in Figure 2. These "damaged widths" were created in order to simulate structure with varying amounts of coating damage. In addition to the variations in damage width, the two wire metallized coatings, aluminum or zinc, were applied in thicknesses of 0.005", 0.010", or 0.020". The overcoat was then applied over the aluminum or zinc. Specimens were prepared with and without the final overcoat. Section 3.1.4.6 contains the test plan.

#### 3.1.4.5 Test Equipment

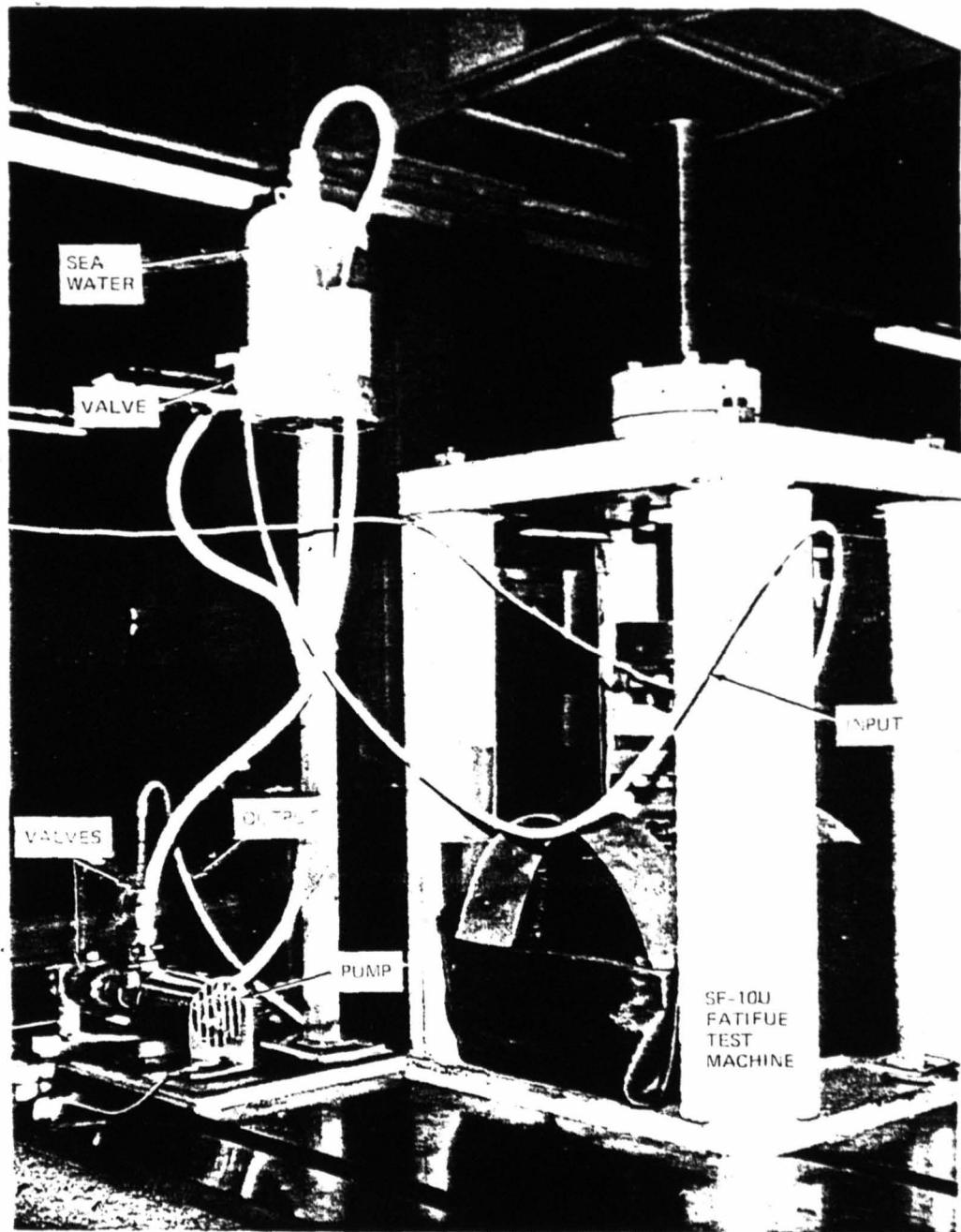
All fatigue tests were conducted at The Boeing Commercial Airplane Company Structures Laboratory. Specimens were tested under axial tension conditions at 1800 cpm in Baldwin SF-10U universal fatigue machines.

A circulating pump system was used to supply a continuous flow of aerated ASTM sea water (ASTM designation D1141-52) to the specimens as they were tested. This pump system (Figure 3) was all plastic to protect against galvanic corrosion. The specimens were wetted by ASTM sea water contained in a plastic bag which enclosed the test section. A specimen under test is shown in Figure 4. A schematic of the system is shown in Figure 5.

#### 3.1.4.6 Test Plan

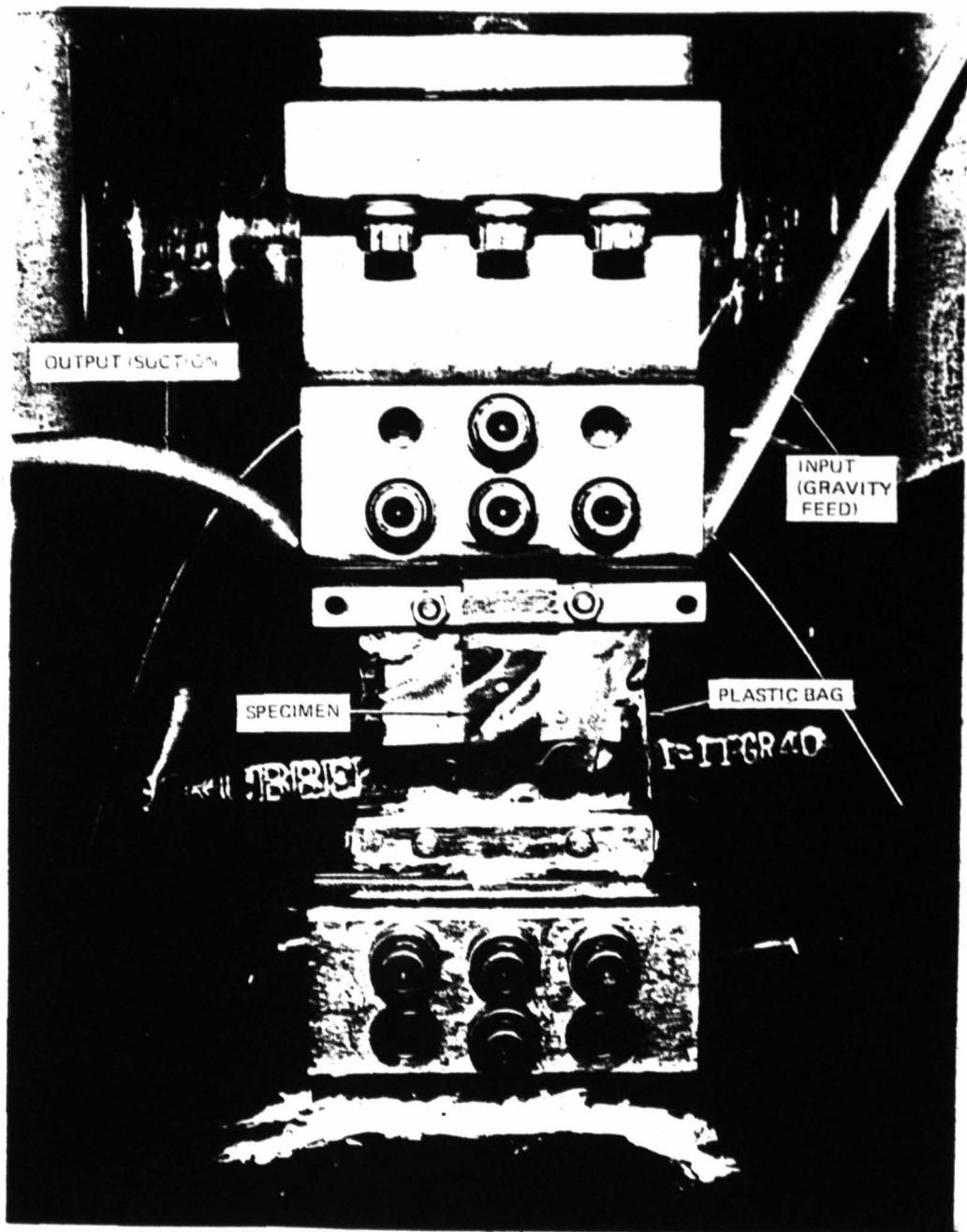
Test variables included wire metallized substrate thickness, substrate material, simulated damage width (described in section 3.1.4.4), presence or lack of an elastomeric overcoat, and pretest exposure time in flowing saltwater. These variables and the specimen numbering system are summarized in Table III.

The salt water exposure, prior to fatigue testing, was conducted at Wrightsville Beach under the direction of the Naval Ship Research and Development Center (NSRDC), Annapolis. Thirty-five specimens were tested with no prior exposure to flowing sea water. Forty-five specimens were tested after exposure for 30 days and



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Figure 3: CORROSION FATIGUE TEST SET UP



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Figure 4: CLOSE UP OF CORROSION FATIGUE TEST SHOWING PLASTIC BAG ENVIRONMENT CHAMBER

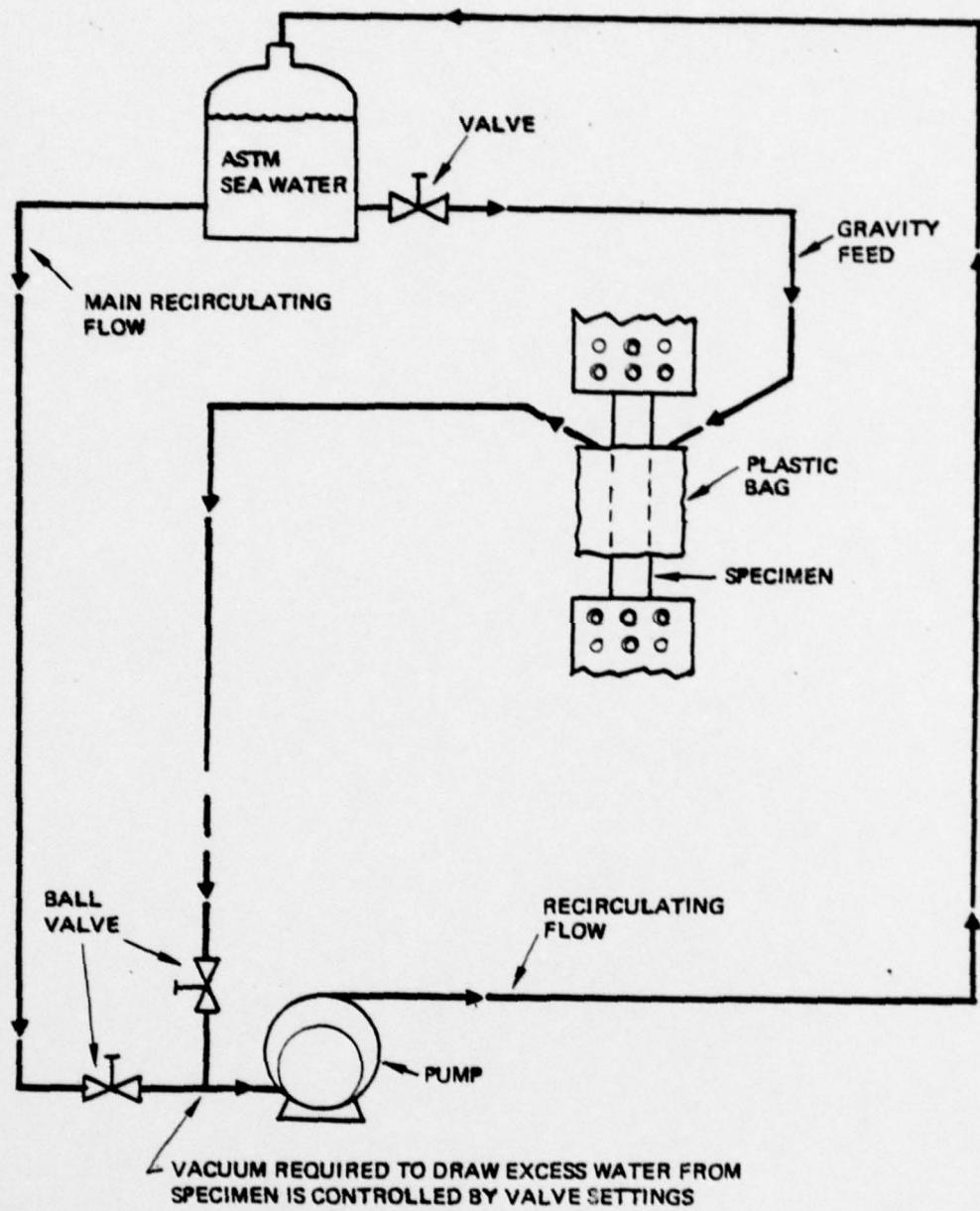


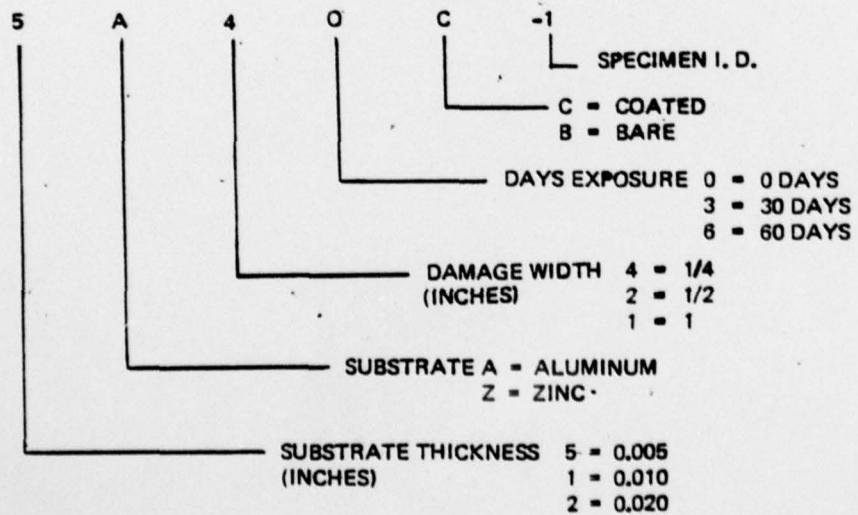
Figure 5: SCHEMATIC OF CORROSION FATIGUE TEST PLUMBING SETUP

Table III: SUMMARY OF TEST VARIABLES

SUBSTRATE THICKNESS (INCHES)	SUBSTRATE MATERIAL	DAMAGE WIDTH (INCHES)	OVERCOATED	QUANTITY TESTED AFTER EXPOSURE TO FLOWING SEAWATER FOR		
				0 DAYS	30 DAYS	60 DAYS
0.005"	ALUMINUM	1/4	YES	3	3	3
		1/2	YES	3	3	
		1	YES	3	3	
		1/4	NO	1	3	
	ZINC	1/4	YES	3	3	
		1	YES	3	3	
0.010"	ALUMINUM	1/4	YES	3	3	3
	ALUMINUM	1/4	NO	1	3	
0.020	ALUMINUM	1/4	YES	3	3	3
		1/2	YES	3	3	
		1	YES	3	3	
		1/4	NO	1	3	
	ZINC	1/4	YES	3	3	
		1/4	NO	1	3	

TOTAL = 89 TESTS

## SPECIMEN NUMBERING SYSTEM



nine specimens were tested after exposure for 60 days.

Room temperature testing of each specimen was conducted with a stress ratio of  $R = 0.06$  and a maximum cyclic stress of either 70 or 80 ksi. Failure was defined as complete fracture of the specimens. Under these conditions, HY130 is at, or near, the endurance limit in air while the fatigue life is only  $5 \times 10^5$  cycles in sea water. (See Figure 1). The test stresses were chosen to delineate the failure of the corrosion protection of the coating system.

### 3.1.5 Presentation and Discussion of Corrosion Fatigue Results

A complete listing of fatigue test results is provided in Tables IV, V and VI, and the results summarized in Figures 6, 7, and 8 for zero, thirty day, and sixty day prior sea water exposures, respectively. In these figures, a set of four symbols are used to describe the type of failure (i.e., in the coating damaged zone, under the coating away from the damaged zone, grip failure, and no failure). Included in these figures are the fatigue lives for unprotected HY130 in sea water at  $\sigma_{max} = 70$  ksi and  $\sigma_{max} = 80$  ksi plus the minimum fatigue life in air at 80 ksi (reference 1). Figures 6, 7, and 8 show that with two exceptions, all specimens experienced test lives longer than unprotected HY130 in sea water. The two exceptions were bare zinc metallized specimens 2Z40B-1 and 5Z43B-2. Examination of specimen 5Z43B-2 showed that a slight surface defect initiated its premature failure. Specimen 2Z40B-1 failed in the grip area.

Two of the primary specimen variables were the active substrate thickness and the duration of exposure to sea water prior to fatigue testing. Three groups of 9 specimens with 0.005", 0.010" and 0.020" aluminum substrate, respectively were each divided into three subsets and exposed to sea water for 0, 30 and 60 days, respectively, prior to fatigue testing. The fatigue test results from these specimens are presented in Figure 9 for easy comparison. It is evident from these results that the prior exposure time has no apparent effect on the results. On the other hand, the thickness of the aluminum substrate appears to have an effect on the results. The fatigue

$\sigma_{MAX} = 70 \text{ KSI}$  80 KSI FAILURE LOCATION

- ■ DAMAGED AREA
  - □ COATED AREA
  - □ NO FAILURE
  - GRIP FAILURE
- $R = 0.06$

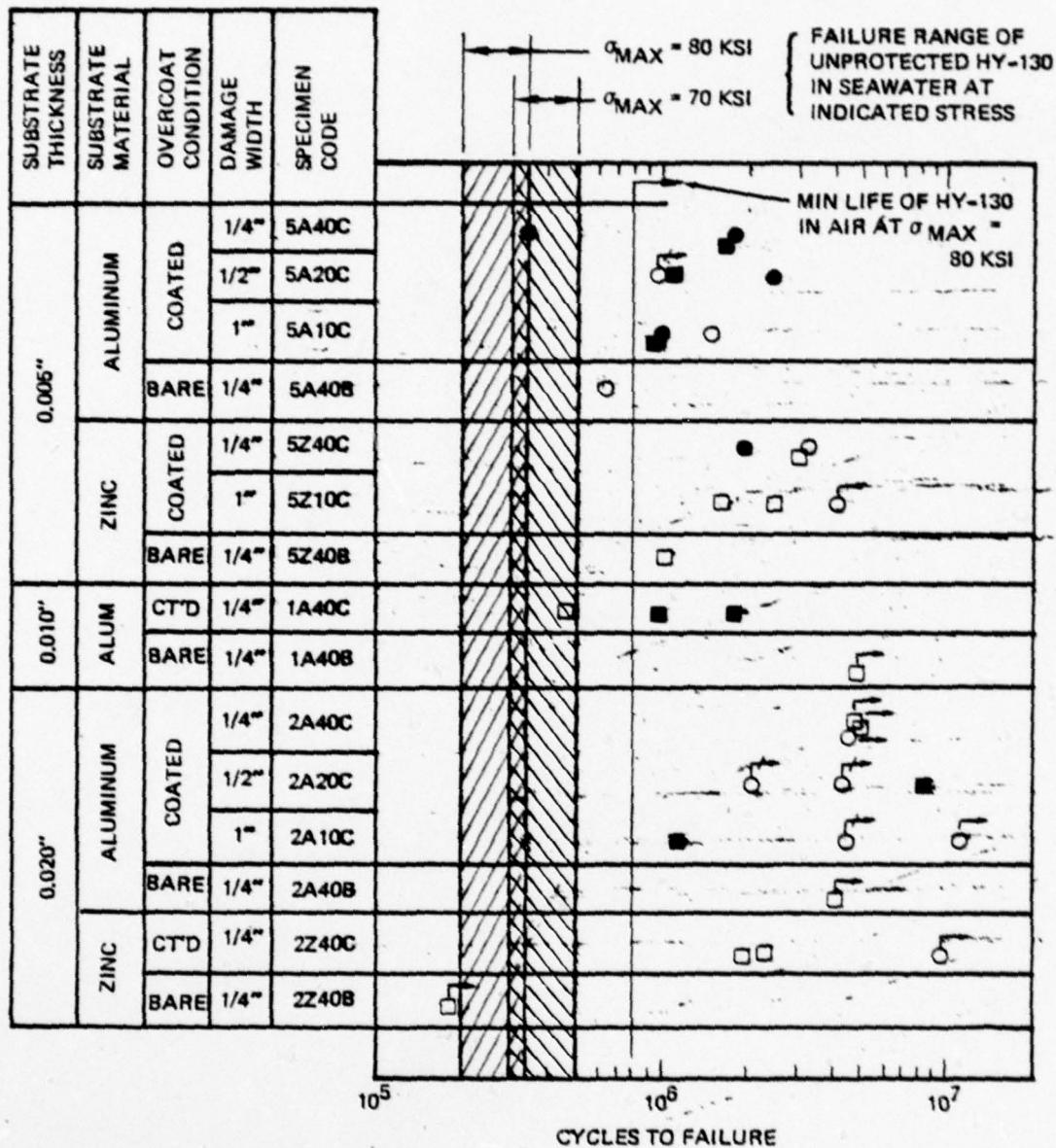


Figure 6: CYCLES TO FAILURE FOR COATED HY-130 FATIGUE SPECIMENS – NO PRIOR EXPOSURE IN FLOWING SEAWATER

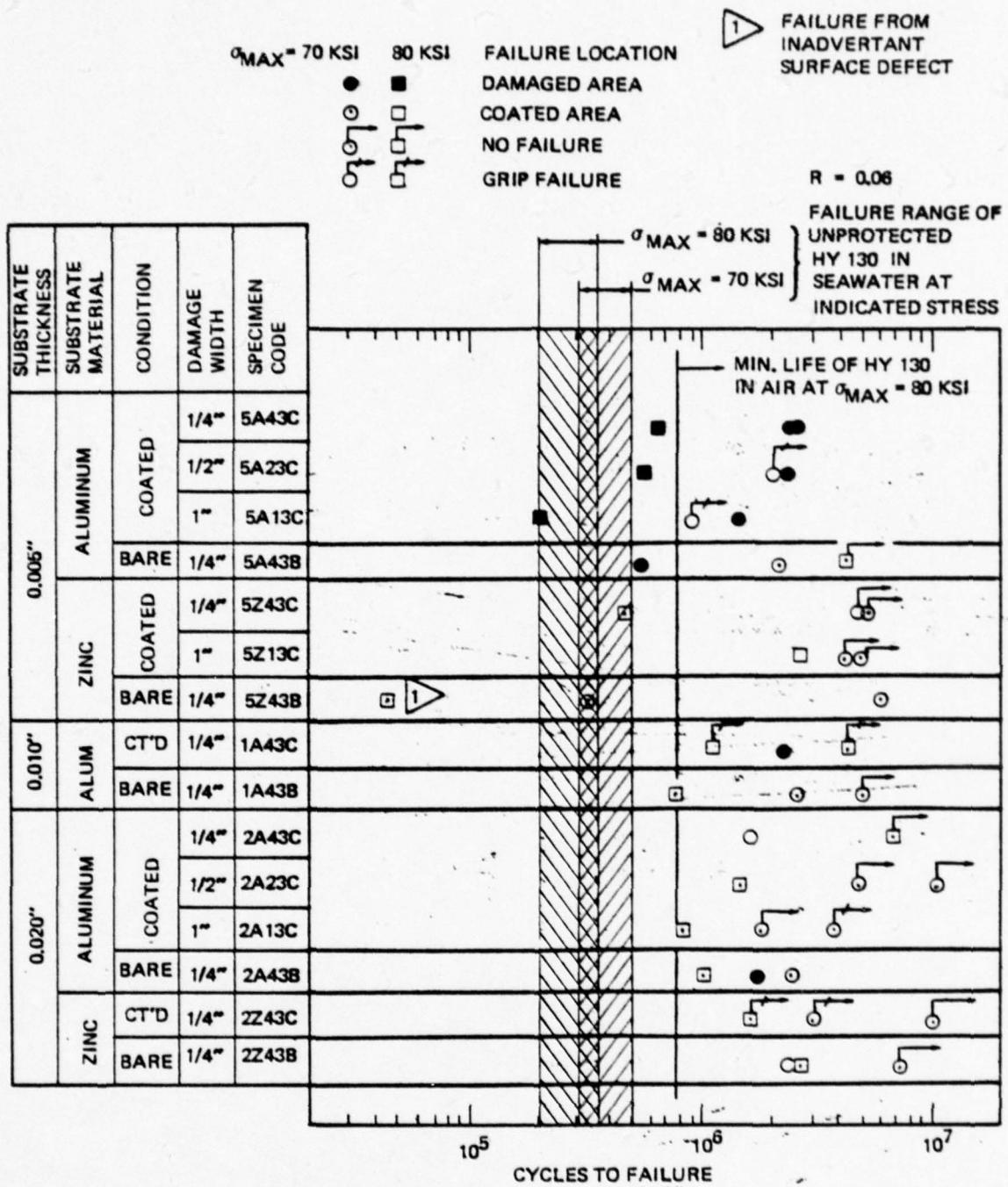


Figure 7: CYCLES TO FAILURE FOR COATED HY 130 FATIGUE SPECIMENS - 30 DAY PRIOR EXPOSURE IN FLOWING SEA WATER

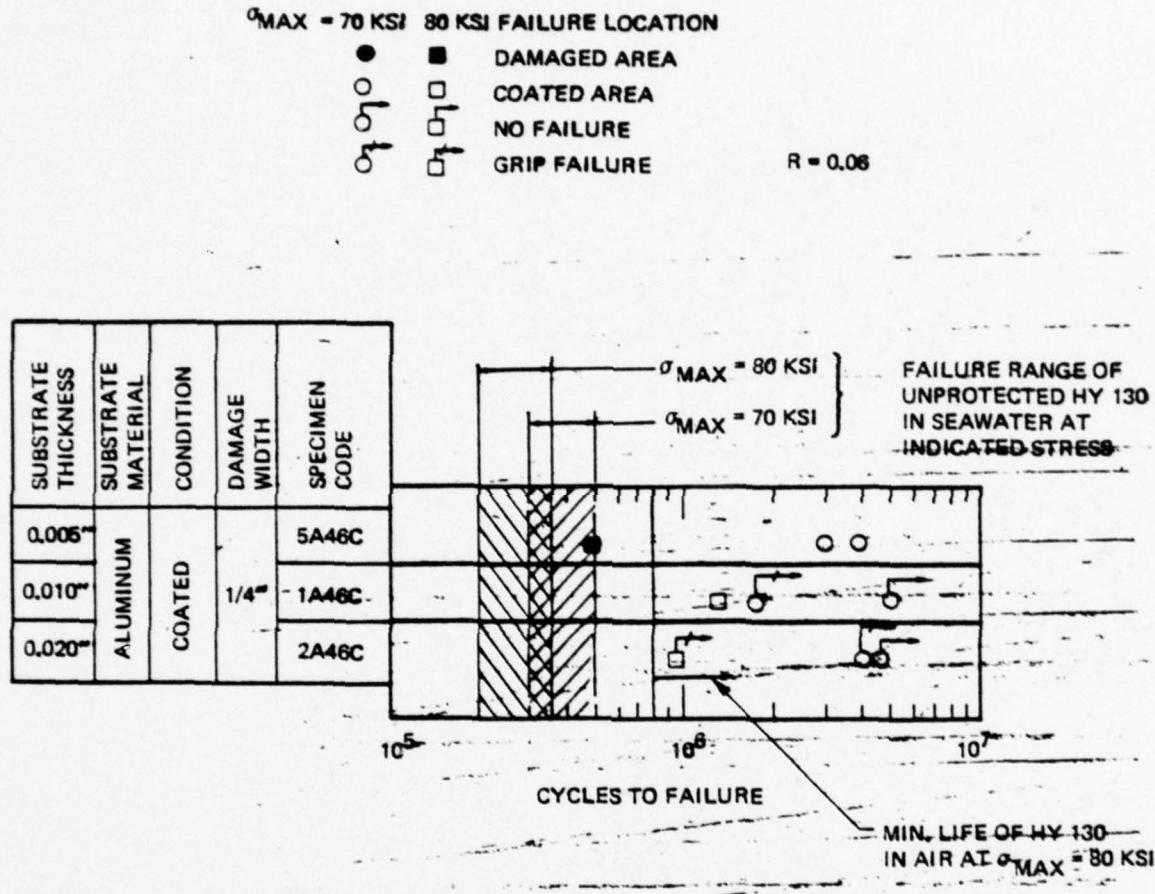


Figure 8: CYCLES TO FAILURE FOR COATED HY 130 FATIGUE SPECIMENS – 60 DAY PRIOR EXPOSURE IN FLOWING SEAWATER

- DAMAGED AREA
- COATED AREA
- NO FAILURE
- GRIP FAILURE

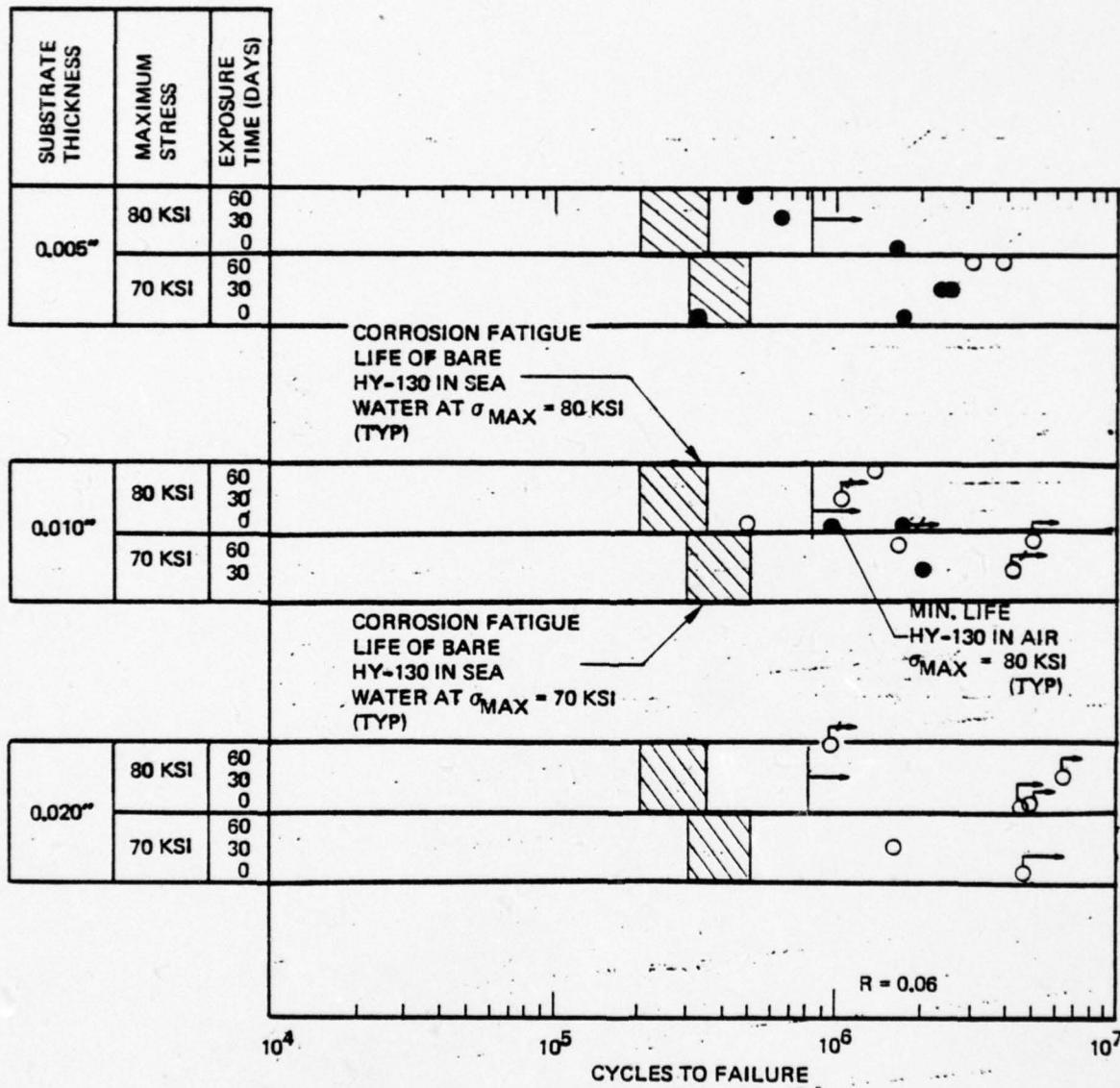


Figure 9: EFFECT OF SEAWATER EXPOSURE TIME - HY 130 STEEL, ALUMINUM SUBSTRATE, 1/4" DAMAGE WIDTH

Table IV: FATIGUE TEST DATA FOR UNEXPOSED COATED H1Y130 STEEL SPECIMENS

SPECIMEN NUMBER	MAX. GROSS AREA FATIGUE STRESS - KSI	CYCLES TO FAILURE	TEST TEMPERATURE	FAILURE ORIGIN	SPECIMEN NUMBER	MAX. GROSS AREA FATIGUE STRESS - KSI	CYCLES TO FAILURE	TEST TEMPERATURE	FAILURE ORIGIN	
5A40C-1	70	331,000	70°F	DA	2A40C-1	80	4,811,000	72°F	NF	
	-2	70	1,780,000	70°F		-2	80	4,977,000	71°F	NF
	-3	80	1,663,000	72°F		-3	70	4,663,000	71°F	NF
5A20C-1	70	2,475,000	70°F	DA	2A20C-1	70	2,121,000	70°F	GF	
	-2	70	978,000	70°F		-2	70	4,305,000	70°F	GF
	-3	80	1,137,000	72°F		-3	80	8,262,000	70°F	DA
5A10C-1	70	1,477,000	70°F	PA	2A10C-1	70	4,490,000	70°F	GF	
	-2	70	945,000	70°F		-2	70	11,193,000	70°F	NF
	-3	80	952,000	71°F		-3	80	1,124,000	72°F	DA
5A40B-1	70	638,000	70°F	PA	2A40B-1	80	4,041,000	72°F	NF	
5Z40C-1	70	1,924,000	70°F	DA	2Z40C-1	80	1,940,000	71°F	PA	
	-2	70	3,331,000	70°F		-2	80	2,351,000	71°F	PA
	-3	80	3,208,000	72°F		-3	70	9,419,000	73°F	NF
5Z10C-1	80	2,459,000	72°F	PA	2Z40B-1	80	181,000	72°F	GF	
	-2	80	1,669,000	70°F		-2				
	-3	70	4,004,000	73°F		-3				
5Z40B-1	80	1,013,000	71°F	PA						
1A40C-1	80	1,799,000	71°F	DA						
	-2	80	476,000	72°F	PA					
	-3	80	946,000	73°F	DA					
1A40B-1	80	4,753,000	71°F	NF						

PA = PAINTED AREA  
NF = NO FAILURE

DA = DAMAGED AREA  
GF = FRIP FAILURE

Table V: FATIGUE TEST DATA FOR COATED HY130 STEEL SPECIMENS EXPOSED 30 DAYS IN FLOWING SEAWATER

SPECIMEN NUMBER		MAX. GROSS AREA FATIGUE STRESS - KSI	CYCLES TO FAILURE	TEST TEMPERATURE	FAILURE ORIGIN	SPECIMEN NUMBER		MAX. GROSS AREA FATIGUE STRESS - KSI	CYCLES TO FAILURE	TEST TEMPERATURE	FAILURE ORIGIN
5A43C	-1	70	2,468,000	72°F	DA	1A43C	-1	70	2,108,000	72°F	DA
	-2	80	646,000	72°F	DA		-2	80	1,077,000	72°F	GF
	-3	70	2,392,000	72°F	DA		-3	70	4,334,000	72°F	GF
5A23C	-1	70	2,385,000	72°F	DA	1A43B	-1	70	2,594,000	71°F	PA
	-2	80	586,000	72°F	DA		-2	80	779,000	71°F	PA
	-3	70	2,027,000	72°F	GF		-3	70	4,900,000	72°F	NF
5A13C	-1	70	1,410,000	72°F	DA	2A43C	-1	70	1,655,000	73°F	PA
	-2	80	210,000	71°F	DA		-2	80	4,000	72°F	1
	-3	70	910,000	72°F	GF		-3	80	6,716,000	73°F	NF
5A43B	-1	70	544,000	72°F	DA	2A23C	-1	70	4,860,000	73°F	NF
	-2	80	4,024,000	72°F	NF		-2	80	1,479,000	72°F	PA
	-3	70	2,162,000	72°F	PA		-3	70	10,010,000	73°F	NF
5Z43C	-1	70	5,162,000	73°F	NF	2A13C	-1	70	1,865,000	74°F	PA
	-2	80	470,000	72°F	PA		-2	80	843,000	72°F	PA
	-3	70	4,948,000	72°F	NF		-3	70	3,780,000	72°F	GF
5Z13C	-1	70	4,317,000	72°F	NF	2A43B	-1	70	2,456,000	72°F	PA
	-2	80	2,633,000	72°F	PA		-2	80	1,032,000	72°F	PA
	-3	70	4,890,000	73°F	NF		-3	70	1,745,000	72°F	DA
5Z43B	-1	70	5,970,000	71°F	PA	2Z43C	-1	70	10,120,000	72°F	NF
	-2	80	43,000	73°F	PA		-2	80	2,591,000	72°F	GF
	-3	70	330,000	72°F	PA		-3	70	4,079,000	72°F	GF
						2Z43B	-1	70	7,378,000	73°F	NF
							-2	80	2,766,000	72°F	PA
							-3	70	2,436,000	72°F	PA

PA = PAINTED AREA  
NF = NO FAILURE

DA = DAMAGED AREA  
GF = GRIP FAILURE

1 ▶ SPECIMEN DAMAGED  
DUE TO MACHINE BREAKDOWN

2 ▶ SPECIMEN APPEARED  
TO HAVE A SURFACE  
DEFECT

Table VI: FATIGUE TEST DATA FOR COATED HY1 130 STEEL SPECIMENS EXPOSED 60 DAYS TO FLOWING SEAWATER

SPECIMEN NUMBER	MAX. GROSS AREA FATIGUE STRESS - KSI	CYCLES TO FAILURE	TEST TEMPERATURE	FAILURE ORIGIN	SPECIMEN NUMBER	MAX. GROSS AREA FATIGUE STRESS - KSI	CYCLES TO FAILURE	TEST TEMPERATURE	FAILURE ORIGIN
5A46C	-1	70	3,014,000	72°F	PA				
	-2	80	493,000	73°F	DA				
	-3	70	3,930,000	74°F	PA				
1A46C	-1	70	1,750,000	72°F	GF				
	-2	80	1,343,000	73°F	PA				
	-3	70	4,904,000	71°F	NF				
2A46C	-1	70	4,088,000	71°F	GF				
	-2	80	940,000	73°F	GF				
	-3	70	4,498,000	72°F	NF				

PA = PAINTED AREA  
NF = NO FAILURE

DA = DAMAGED AREA  
GF = GRIP FAILURE

lives were generally shorter for the 0.005" substrate although they were in most cases better (longer) than for bare HY130 in sea water. In addition, almost all of the failures for the 0.005" aluminum substrate were in the damaged zone, whereas fewer failures were in the damage zone for the 0.010" substrate, and two occurred in the 0.020" substrate. The data from the 0.005" and 0.020" aluminum substrate specimens are further summarized in Figures 10 and 11 respectively. These figures show the data plotted on the S-N curves for uncoated HY130 from reference 1.

This same substrate thickness effect is discernible for the entire body of tests. A summary of the number of specimens which failed in the damaged area is given in Table VII. 71.5% of the 0.005" aluminum substrate specimens failed in the damaged zone, 33.3% at 0.010", and 10.0% at 0.020". In the case of the zinc substrate, the numbers are 8.3% for 0.005" thickness and 0% for 0.020". It is important to note that with the exception of some .005" aluminum substrate specimens, the fatigue lives of all the specimens approached that of HY130 in air.

A third major specimen variable was the "damage" area width. This variable had little or no effect on the results. A summary of the number of specimens which failed in the damaged area, broken down by damage width, is given in Table VIII. For the aluminum substrate, 38.5% of the 1/4" damage width specimens failed in the damaged area, very nearly the same percent - 41.6% - had similar fates for both the 1/2" and 1.0" damage width specimens.

As shown in Tables VII and VIII, the zinc substrate protected the specimens better than did the aluminum. However, the zinc substrate had a tendency (80-90%) to delaminate from the specimen under the fatigue loading conditions. Examples of this delamination are shown in the photographs of Figure 12. Figure 12A shows aluminum substrate specimens without delaminations and Figure 12B shows comparable zinc substrate specimen with delaminations. Aluminum did much better with respect to delamination although the 0.020" aluminum specimens showed some delamination as shown in Figure 12C. Figures 13, 14 and 15 show typical specimens after exposure to 30 day and 60 day flowing salt water prior to fatigue testing. The aluminum specimens had more brown iron oxide in the damaged area than the zinc specimens. The

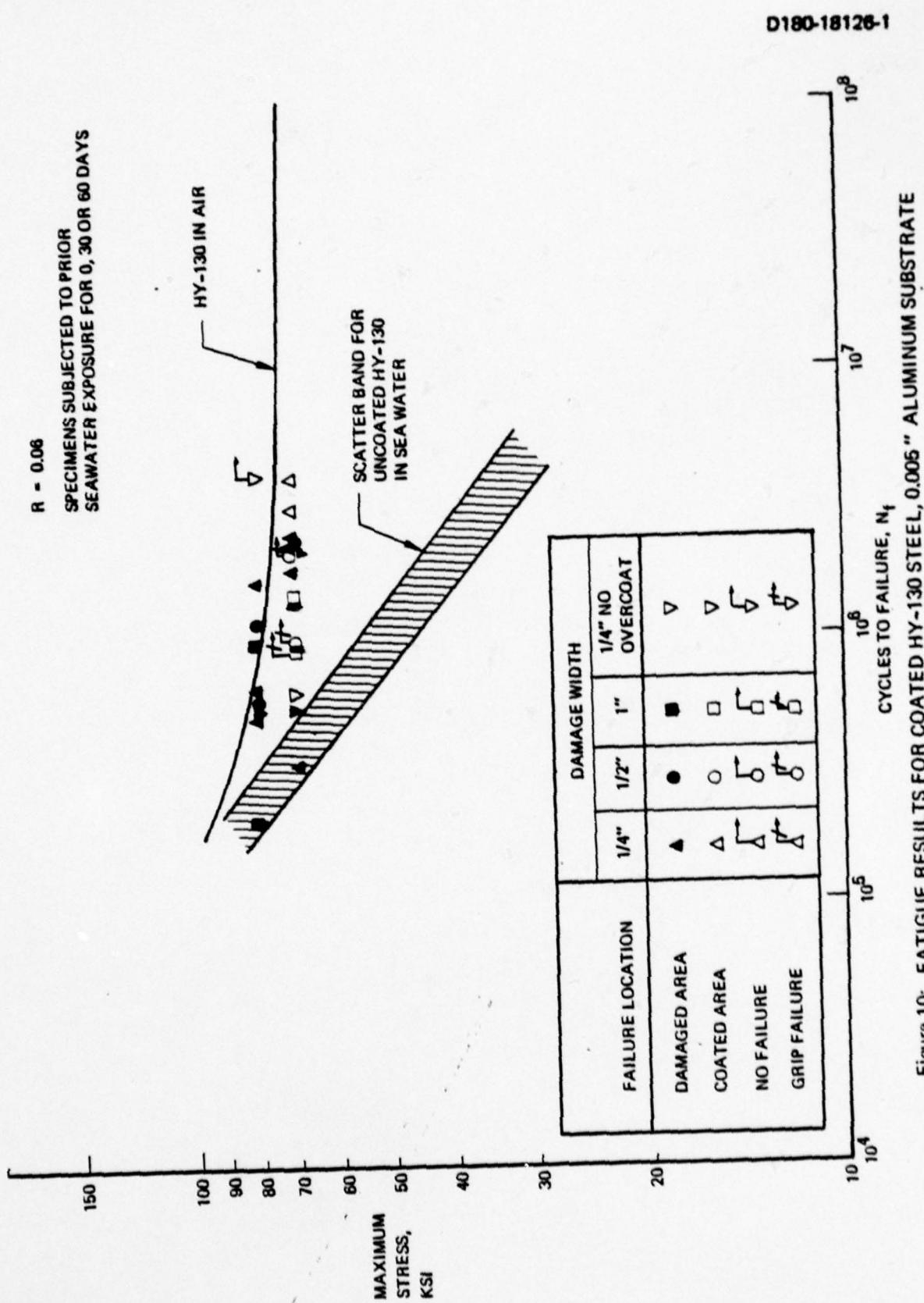


Figure 10: FATIGUE RESULTS FOR COATED HY-130 STEEL, 0.005" ALUMINUM SUBSTRATE

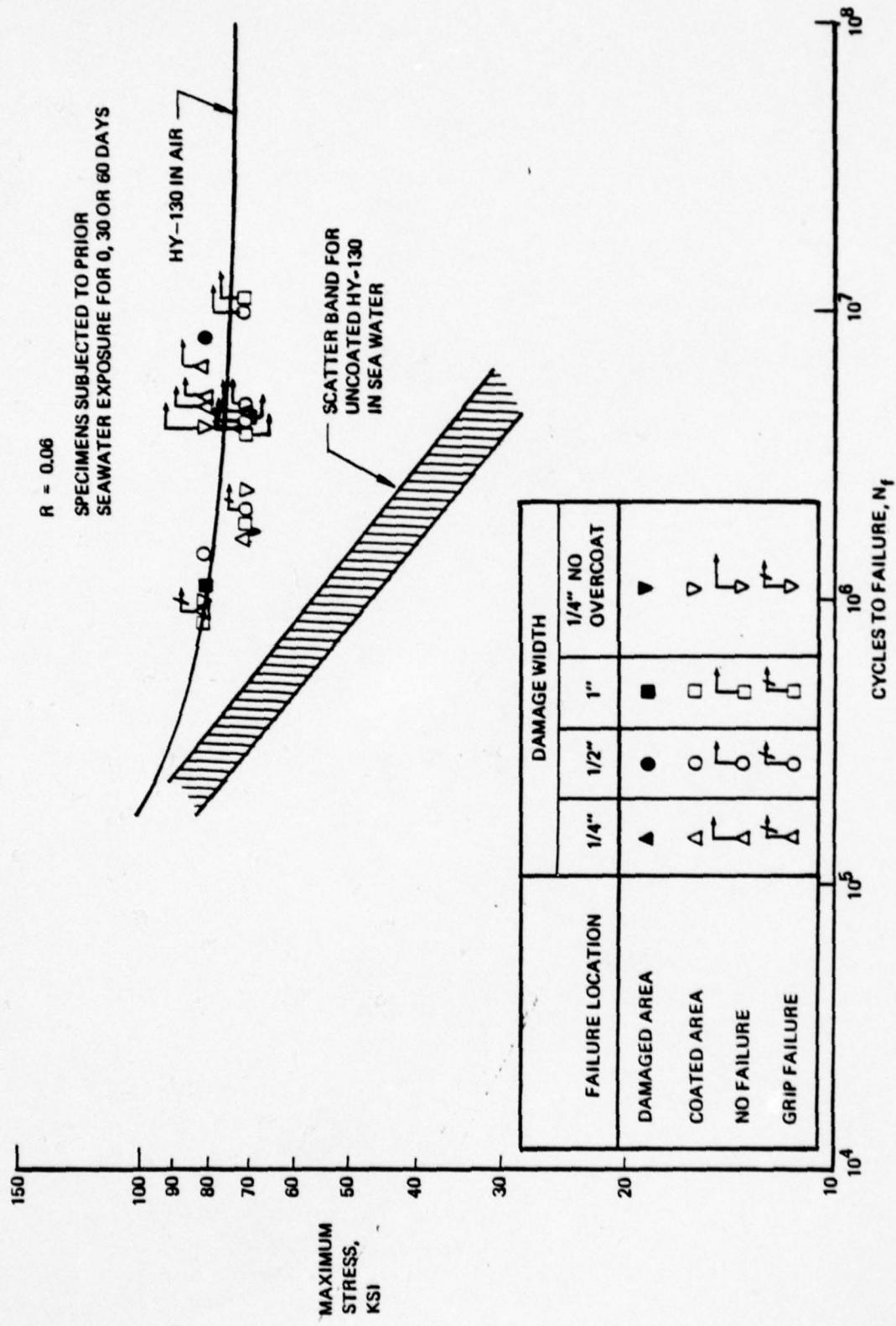
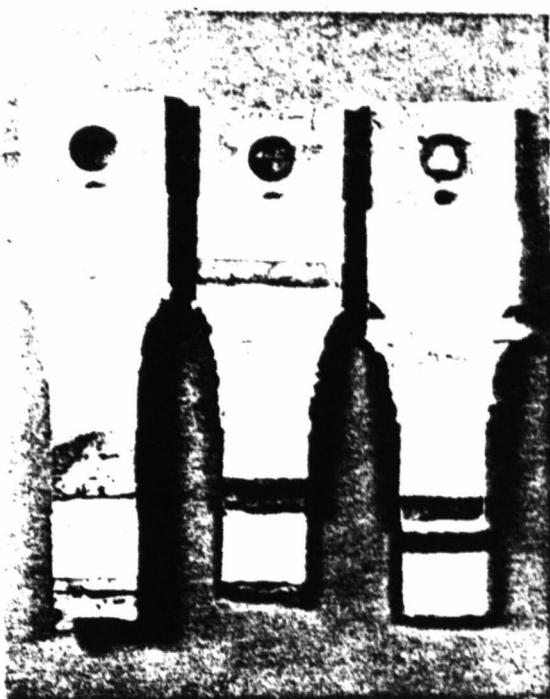
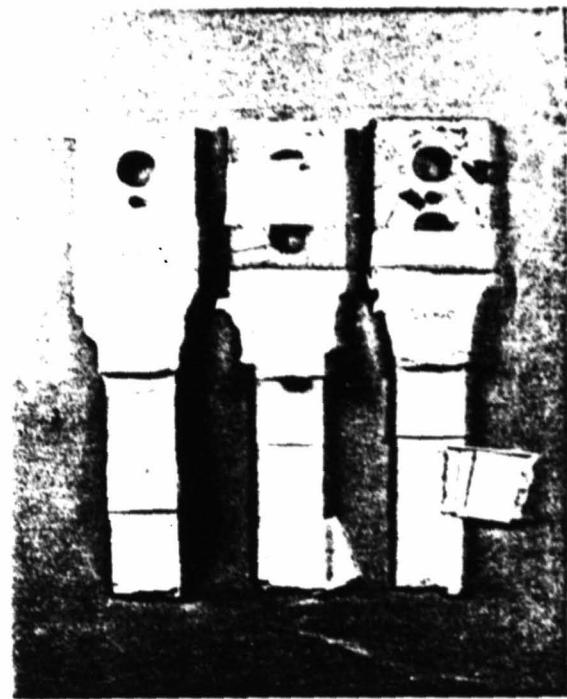


Figure 11: FATIGUE RESULTS FOR COATED HY-130 STEEL, 0.020" ALUMINUM SUBSTRATE

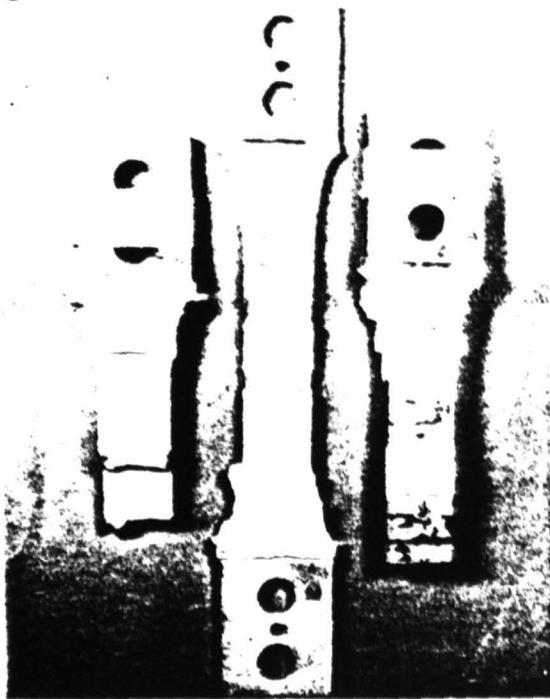
A



B



C

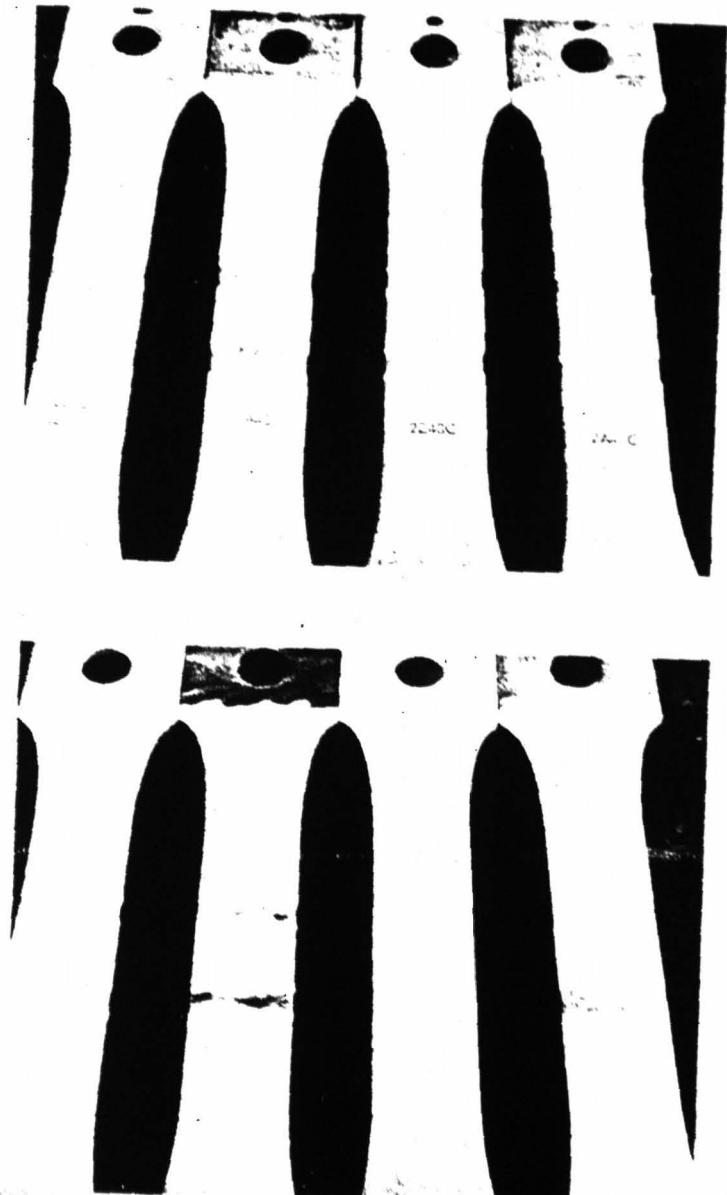


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Figure 12:

TYPICAL TESTED FATIGUE SPECIMENS

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Figure 13: SPECIMENS AFTER 30 DAYS EXPOSURE TO  
FLOWING SEA WATER

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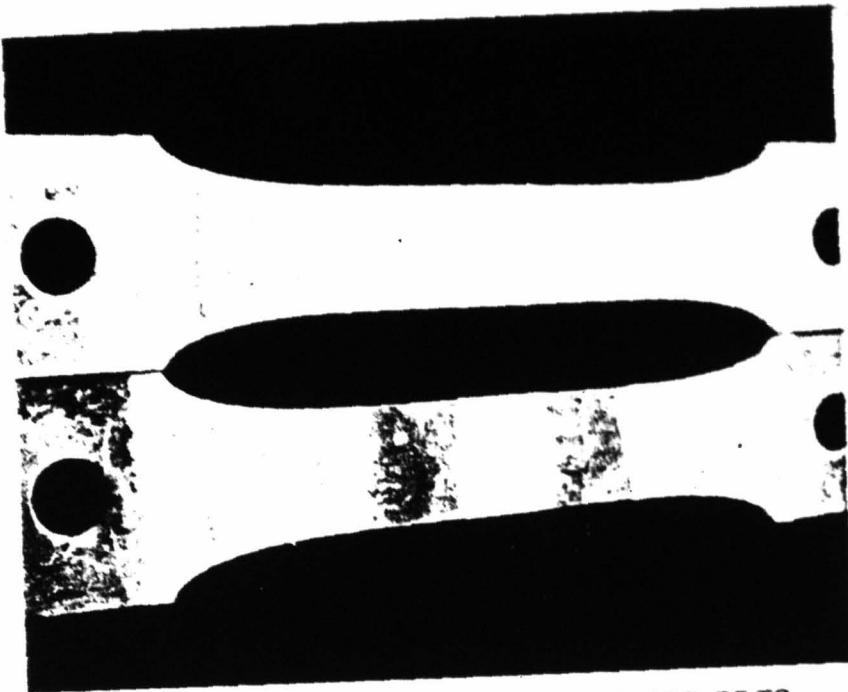


Figure 14 SPECIMENS AFTER 30 DAYS EXPOSURE TO  
FLOWING SEA WATER

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Figure 15. FATIGUE SPECIMENS AFTER 60 DAY EXPOSURE TO FLOWING SEA WATER

Table VII: NUMBER OF FAILURES IN "DAMAGED" AREA AS A FUNCTION OF  
SUBSTRATE THICKNESS AND EXPOSURE TIME, SPECIMENS WITH  
OVERCOAT ONLY

SUBSTRATE	EXPOSURE TIME (DAYS)	SUBSTRATE THICKNESS					
		0.006	0.010	0.020	0.040	0.060	0.080
ALUMINUM	0	1/4	1/2	1.0	1/4	1/2	1.0
	30	3/3	2/3	2/3	2/3	—	—
	60	1/3	—	—	0/3	—	—
TOTAL		7/9	4/6	4/6	3/9 = 33.3%	0/8	1/6 1/6
ZINC					16/21 = 71.5%	2/20 = 10%	
0		1/3	—	0/3	—	—	—
30		0/3	—	0/3	—	0/3	—
TOTAL		1/6	—	0/6	—	0/6	0/6 = 0%
				1/12 = 8.3%			

X/Y = NUMBER OF FAILURES IN DAMAGED AREA/NUMBER OF SPECIMENS TESTED

Table VIII: NUMBER OF FAILURES IN "DAMAGED" AREA AS A FUNCTION OF  
DAMAGE WIDTH AND SUBSTRATE THICKNESS - SPECIMENS WITH  
OVERCOAT ONLY

EXPOSURE TIME (DAYS)	SUBSTRATE MATERIAL	SUBSTRATE THICKNESS (INCH)						0.020"
		0.006"	0.010"	0.010"	0.010"	0	30	
1/4"	ALUMINUM	3/3	3/3	1/3	2/3	1/3	0/3	0/3
	ZINC	1/3	0/3	-	-	-	0/3	0/3
1/2"	ALUMINUM	2/3	2/3	-	-	-	1/3	0/3
	ZINC	2/3	2/3	-	-	-	1/3	0/3
1"	ALUMINUM	0/3	0/3	-	-	-	-	0/0
	ZINC	0/3	0/3	-	-	-	-	0/0

8/16    7/16    1/3    2/3    1/3    0/3    2/12    0/11    0/3    21/68 = 30.9%  
 16/33 = 48.5%    3/9 = 33.3%    2/26 = 7.7%

X/Y = NUMBER OF FAILURES IN DAMAGED AREA/NUMBER OF SPECIMENS TESTED

5 mil aluminum specimens show more corrosion in the damaged area than the 10 and 20 mil specimens. The aluminum specimens have more blisters in the passive topcoat at the edge of the damage area and the blistering is more extensive on the 10 and 20 mil than on the 5 mil aluminum. Blistering of the passive overcoat has extended further into the undamaged area on the 60 day specimens.

Several coatings tested in our Company funded research programs (PR 1654, Hughson M-312, and Glidden Glidflake) have shown less tendency to blister over the aluminum metallizing when tested under identical conditions. In all cases observed, the blistering progressed inward from the damage area indicating corrosion of the metallized coating. Additional work should be done to investigate the blistering problem, test some of the more promising coatings, and investigate the possible use of a chemical conversion coating over the metallizing before overcoating.

As the last major specimen variable, some specimens were tested with an elastomeric coating over the active substrate. The results are inconclusive in that some sets of non-overcoated specimens showed better lives than their coated counterparts while others were unchanged or showed shorter lives. This can be seen by examining Figures 6, 7, and 8, or Tables IV, V, and VI.

### 3.1.6 Conclusions From Corrosion Fatigue Tests

All combinations of substrate material, substrate thickness and damage width tested provided improvement in the corrosion fatigue strength of HY130 in sea water.

The following conclusions were made with respect to the test variables:

- o Prior exposure had no apparent influence on the corrosion fatigue life protection provided by the coating system.
- o The zinc substrate provided better protection than did the aluminum substrate; however, it was more susceptible to delamination.
- o Damage widths studied (1/4", 1/2" and 1") had no apparent influence on the corrosion fatigue life protection provided by the coating system.

- o The zinc substrate as applied on the test specimens exhibited excessive delamination.
- o With the exception of the .005" aluminum substrate, all of the substrate material/gage combinations tested provided significantly improved corrosion fatigue strength; the .005" aluminum substrate provided a smaller improvement.
- o The Laminar X-500 coating blistered over both the zinc and aluminum metallizing. The blistering was more extensive over aluminum. Several other coatings (PR 1654, Hughson M-312, and Glidden Glidflake) tested under company funded research exhibited little or no blistering. Additional work should be done to select overcoats that will eliminate or minimize the blistering problem.

### 3.2 Repair Materials and Techniques

#### 3.2.1 Background

A continuous protective coating is a firm requirement for successful operation of HY130 in a sea water environment. During operation, breaks in the external coatings can be anticipated due to flexure of the structure, and impact and abrasion from debris. Breaks in the coating should be repaired in the field prior to dockside or dry-dock repair to minimize the amount of corrosion and to prevent ventilation during flying due to non-uniform surfaces.

Two types of repair were studied, an emergency type repair that could be accomplished in less than one hour and a backup type repair that could be accomplished in 12 hours that would have a service life up to 6 weeks. These repairs would be considered an interim fix until the original coating could be restored during dockside or dry-dock refurbishment.

Two coating systems were chosen to be representative of those that might be repaired in actual service; The Laminar X-500 system now used on the USS PLAINVIEW

(AGE (H)-1) and the USS HIGHPOINT (PC (H)-1) and the Hughson 9924 primer and PR 1654 topcoat system that Boeing research has shown to be a leading candidate for coating strut and foil external surfaces. Repairing these two coatings was expected to be significantly different in that one is applied to a total coating thickness of 20 to 30 mils (PR 1654) and the other to a thickness of 4 to 6 mils (Laminar X-500). Therefore, since the same repair material may not be suitable for both, the two would be representative of a range of coatings that might be used.

### 3.2.2 Test Objectives

The objective of this program was to develop two levels of field repair of damaged HY130 coated structure, principally hydrofoil strut/foil hardware. These two levels of repair were:

- (1) A repair period up to one hour for emergency use.
- (2) A repair period of up to 12 hours for an interim service life of 4 to 6 weeks.

### 3.2.3 Test Materials

A survey was made of the Boeing Material Specification System, vendors and vendor literature, and appropriate materials technology groups to determine what materials were available that might have a 1 or 12 hour cure time and properties of flexibility and erosion resistance to withstand the struts and foils environment. These materials were then tested according to the test plan.

- A. BMS 5-29 - Type 3 - Class I  
Epoxy-polyamide adhesive filled with up to 6% CAB-O-SIL 
- B. BMS 5-29 - Type 2 - Class II  
Epoxy-polyamide adhesive 
- C. BMS 5-102 - Type I  
Thixotropic Epoxy Adhesive 
- D. PR 1654 coating patch applied using Weldwood Contact Cement, U.S.  
Plywood - Champion Papers, Inc., as an adhesive.

- E. Epoxy-Patch #615 Blue - Hysol Division - The Dexter Corporation
- F. Glidden Glidflake - Polyester Coating Material
- G. PR 1653 Polyurethane repair material - Products Research and Chemical Corporation
- H. PR 1654 Polyurethane Coating - Products Research and Chemical Corporation
- I. Hysol EA960F Structural Adhesive - Hysol Division - Dexter Corporation
- J. 3M Adhesive XA-3517 Non-Flow Adhesive. Adhesives, Coatings and Sealers Division - 3M Company
- K. BMS 5-92 Type I - Modified Epoxy Adhesive 
- L. BMS 5-79 B-1/2 - Pressure, Environmental, and Fuel Cavity Sealant 
- M. Epoxy Primer, Mare Island Experimental Formula 1B-53 Pro-Line Paint Company

 BMS denotes that a Boeing Material Specification is available for these materials and that these materials were purchased to these specifications.

### 3.2.4 Test Procedures

#### 3.2.4.1 Specimen Configuration

The basic specimen for erosion testing was 3" x 8" x .200" HY130 steel. Both bare HY130 and wire metallized HY130 specimens were coated with PR 1654 or Laminar X-500. The coating was damaged in an area approximately 1" x 3" in the center of the specimen.

#### 3.2.4.2 Application of Coatings

Aluminum wire metallizing was applied per the process described in Section 3.1.4.2. After metallizing, the specimens were protective wrapped and just prior to application of the organic coating, they were solvent cleaned using methyl ethyl ketone or acetone. The bare HY130 steel specimens were grit blasted and solvent cleaned

just prior to application of the coatings.

The Laminar X-500 coating system was applied using the procedures described in Section 3.1.4.3. The same spray techniques were used to apply the Hughson 9924 primer and the PR 1654 topcoat per the following schedule:

1. Applied Hughson Wash Primer 9924 (Hughson Chemical Co.) to a dry film thickness of 0.25 to 0.50 mil. Allowed primer to dry 1 hour.
2. Applied PR 1654 Polyurethane Coating (Products Research & Chemical Corporation) to a dry film thickness of 25 ± 3 mils.

The coating was then allowed to cure a minimum of 7 days.

#### 3.2.4.3 Surface Preparation for Repair

Several methods were tried to damage the coatings such as cutting and peeling, sanding, and wire brushing. Power wire brushing using a drill motor worked well to remove the PR 1654 coating and left the edge of the coating faired in very nicely. For the Laminar X-500 power sanding using a rotary sanding disc worked well. In all cases the primer was removed with the base coating. An orbital sander with 180 grit garnet or aluminum oxide paper was used as a final preparation for both types of coating to fair in the edge to the damage area and to insure a bright metal surface in the damage area. The damage area was then solvent wiped with methyl ethyl ketone or acetone as a final preparation.

The surface preparation techniques did not remove the aluminum metallizing, therefore no attempt was made to re-metallize the repair area. It was felt that the metallizing process did not lend itself easily to shipboard operations and if the repair materials during erosion testing exhibited a service life over bare steel equal to the service life of the coating material over either aluminum metallizing or bare steel, then reapplying the metallizing would not be necessary.

Several surface preparation tests were conducted using panels that had a damaged coating and base metal corrosion. Attempts were made to remove the corrosion by

both mechanical means (power sanding and power wire brushing) and by chemical solutions such as Naval Jelly and a phosphoric acid cleaner per MIL-M-10578 Type I (Turco W.O.1, Turco Products, Incorporated). The mechanical method proved to be the more satisfactory since it was faster and accomplished both preparing the base metal surface and fairing in the coating edge at the same time.

#### 3.2.4.4 Repair Procedures

##### 3.2.4.4.1 Application of Repair Materials

The filled epoxy adhesives such as BMS 5-102 Type 1, Hysol EA960F, Epoxy-Patch #615 Blue and the PR 1653 polyurethane repair material were applied using a spatula. The material was applied in excess of that necessary to fill the damage area, the excess was then scraped off leaving as smooth a surface over the damage area as possible. This was accomplished by using a straight edge or squeegee, that would span the damage area. The BMS 5-29, Type 2 Class II and BMS 5-29, Type 3 Class I epoxy adhesives, Glidden Glidflake, PR 1654 polyurethane coating and the 1B53 primer were applied using a brush.

The technique used for applying the PR 1654 patch material was to cut the patch as close as possible to just overlap the damage area, the contact adhesive was then applied to both the patch and the damaged area and allowed to dry for 15 minutes or until the surface became glossy. The patch was then pressed onto the damage area and was ready to be sanded to fair in the edges.

##### 3.2.4.4.2 Curing of Repair Materials

All the materials to be tested as 1 hour repair materials, except the patch applied with contact cement, were cured for 30 minutes at a temperature of 180°F - 200°F (see Section 3.2.4.6.1). The contact cement bonds immediately without the application of heat.

The materials to be tested as 12 hour repair materials were cured at 150°F (see Section 3.2.4.6.2) for up to 2 hours followed by a room temperature cure of 6 hours.

#### 3.2.4.4.3 Surface Preparation Prior to Testing

Immediately after curing, the surface of the repair was sanded either by hand or with an orbital sander using 180 to 240 grit garnet or aluminum oxide paper. This removed any sharp edges and smoothed out any transition between the repair and the coating.

#### 3.2.4.5 Test Equipment

Erosion testing was accomplished in the testing apparatus shown in Figures 16 and 17. The test conditions were: water velocity of 52 knots and water temperature of  $100 \pm 5^{\circ}\text{F}$ . The water velocity of the test apparatus is adjusted by controlling the flow through the valve to the cross tee (Figure 16) to maintain the pressure necessary to obtain 52 knots at the nozzle as shown in the calibration curve in Figure 18. The water temperature is controlled by a cold water cooling coil in the sump.

#### 3.2.4.6 Test Plan

##### 3.2.4.6.1 Screening Tests (One hour repair)

The basic criterion for screening the available one hour repair materials was that they must cure to a working hardness (able to be sanded) in 30 minutes at a temperature not to exceed  $200^{\circ}\text{F}$ . The temperature of  $200^{\circ}\text{F}$  was chosen by determining what temperature we could maintain over a 25 sq.in. area using a portable hot air blower (Model HG501L26 Heat Gun, Master Appliance Corp., Racine, Wisconsin).

The materials listed in Section 3.2.3 were screened as possible candidates for one hour repair. All materials were tested in thicknesses of both 5 and 25 mils since this is the range of thicknesses of the coatings that would be repaired.

Of the materials screened for cure time, the following passed the initial criteria:  
A, B, C, D, E, F, G, I and M.

Item D is a repair method that was accomplished by spraying PR 1654 polyurethane coating onto a mylar sheet to thicknesses of 25 mils and 5 mils. After these films had cured, they were then removed and cut into suitable shapes for patches to be bonded with an adhesive for a quick repair. All other repair systems were applied as a coating material over the repair.

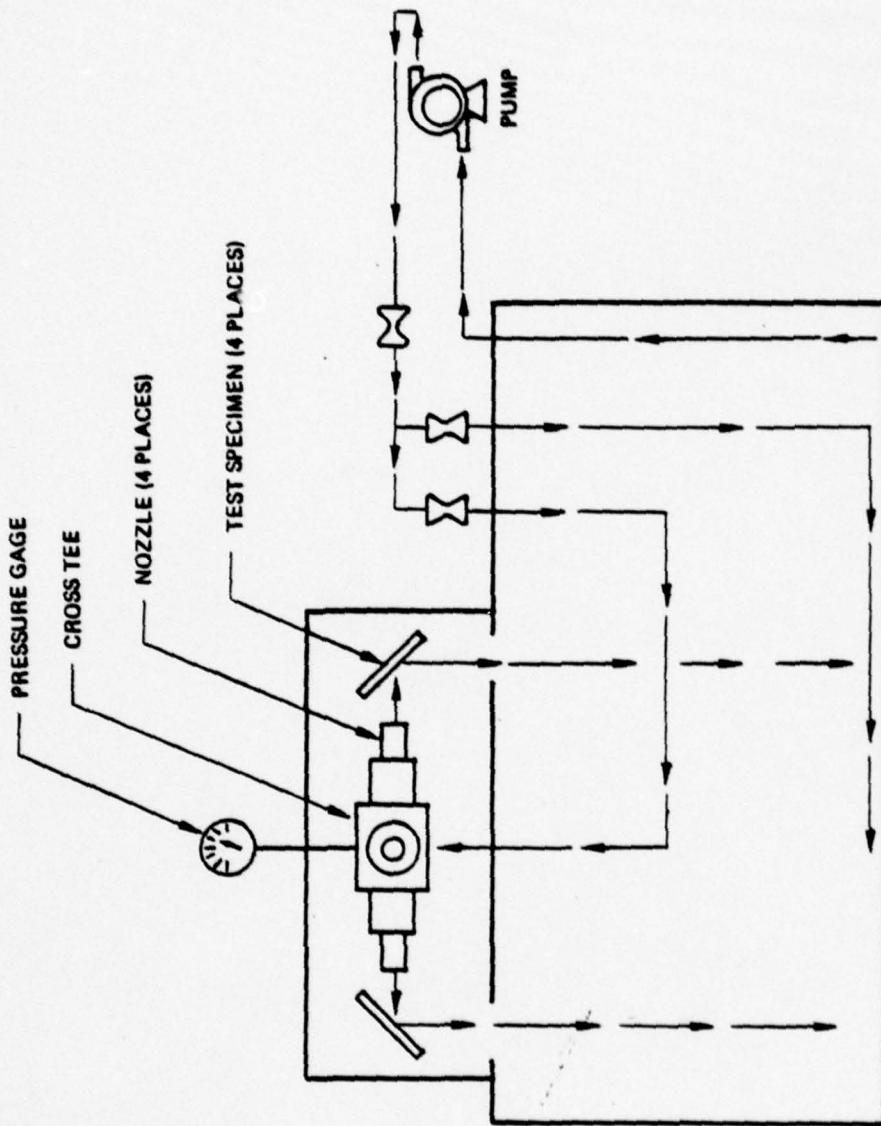
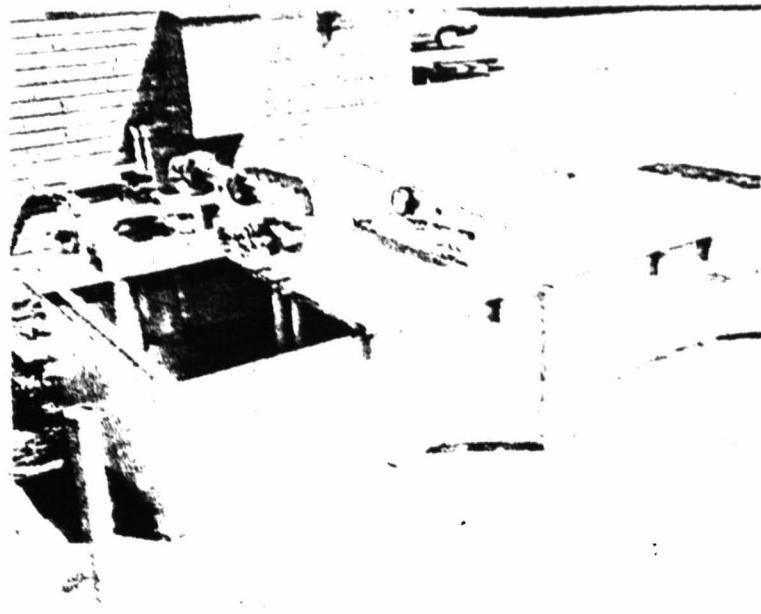
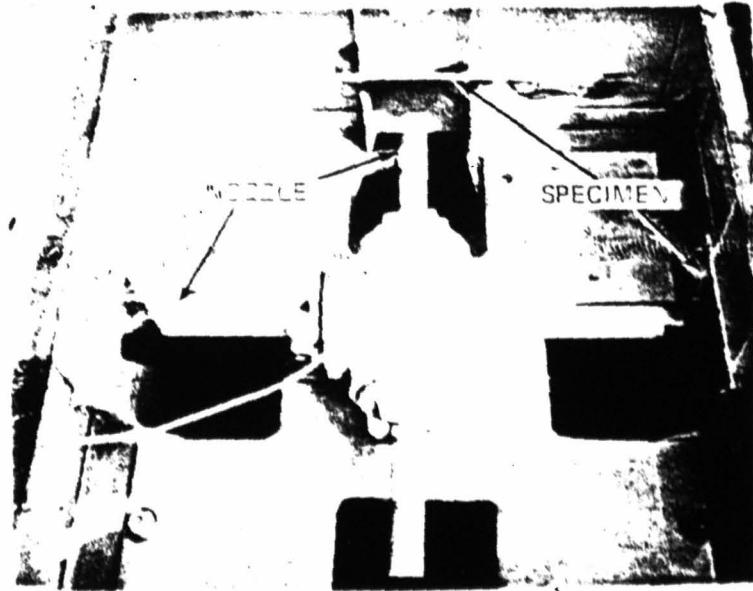


Figure 16: SCHEMATIC OF SALT WATER EROSION TEST FACILITY

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OVERALL VIEW



VIEW OF NOZZLES AND SPECIMENS

Figure 17: SALT WATER EROSION TEST FACILITY

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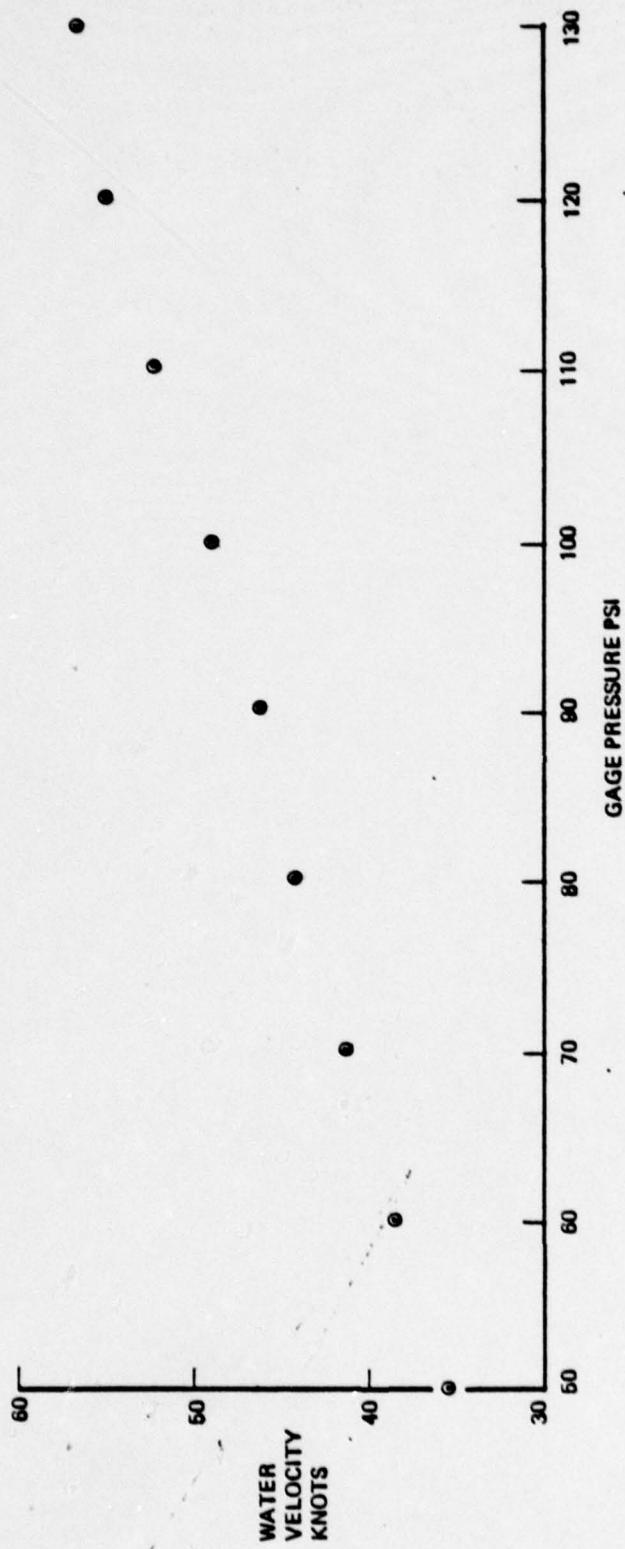


Figure 18: GAGE PRESSURE VS WATER VELOCITY AT NOZZLE –  
SALT WATER EROSION TEST FACILITY

These materials were then tested further by using the erosion testing procedures described in 3.2.4.5. Application properties of the materials were also evaluated as the specimens were being prepared for erosion testing.

#### 3.2.4.6.2 Screening Tests (12-Hour Repair)

The materials that failed to meet the cure time requirements for the one hour repair were then checked to determine if they would cure to a sanding hardness within 2 hours at 150°F followed by 6 hours at 70°F. The cure time criterion was arrived at by assuming that the repair area could be as large as 50 square inches and that approximately 3 hours would be used to prepare the surface and apply a primer if necessary. The only material that met this requirement was the PR 1654 Polyurethane Coating.

This material was then tested further using the erosion testing procedures described in 3.2.4.5 and evaluating application properties during application.

#### 3.2.5 Discussion of Test Results

During application of the repair materials it became obvious that materials such as the filled epoxies (BMS 5-102, Epoxy Patch #615 and Hysol EA960F), the polyurethane repair material (PR1653) and the polyester material, (Glidflake) were the easiest to apply to obtain a smoothly filled damage area. The BMS 5-29 adhesives were not satisfactory for filling the damage area due to their property of becoming more fluid as they are heated. On anything but a horizontal surface they would run badly before setting up.

The patch repair method using contact cement has an advantage in that it will bond at ambient temperatures; however, it is difficult to obtain a smoothly faired transition between the patch area and the coating. The IB53 primer worked well as a quick repair material for the Laminar X-500 coating which was approximately 5 mils thick. Two brush coats of the primer filled the repair depression up to the original thickness. However, the primer could not be brushed on thick enough in two coats

to fill the repair depression in the PR 1654 coating which was 20 to 30 mils thick.

The erosion testing results are shown in Table IX and typical specimens after testing are shown in Figure 19 and 20. The erosion testing zones are at the point of direct impingement from the nozzle and the splash zones are on each side of this area.

The polyurethane repair material PR1653 exhibited fair erosion life in some instances; however, even the 12 hour repair cure period was marginal for this material to develop enough strength to withstand the erosion forces.

The BMS 5-102 filled epoxy adhesive did not protect well in the thin film application over the Laminar X-500 coating although the erosion resistance was good in the repair of the PR1654 coating.

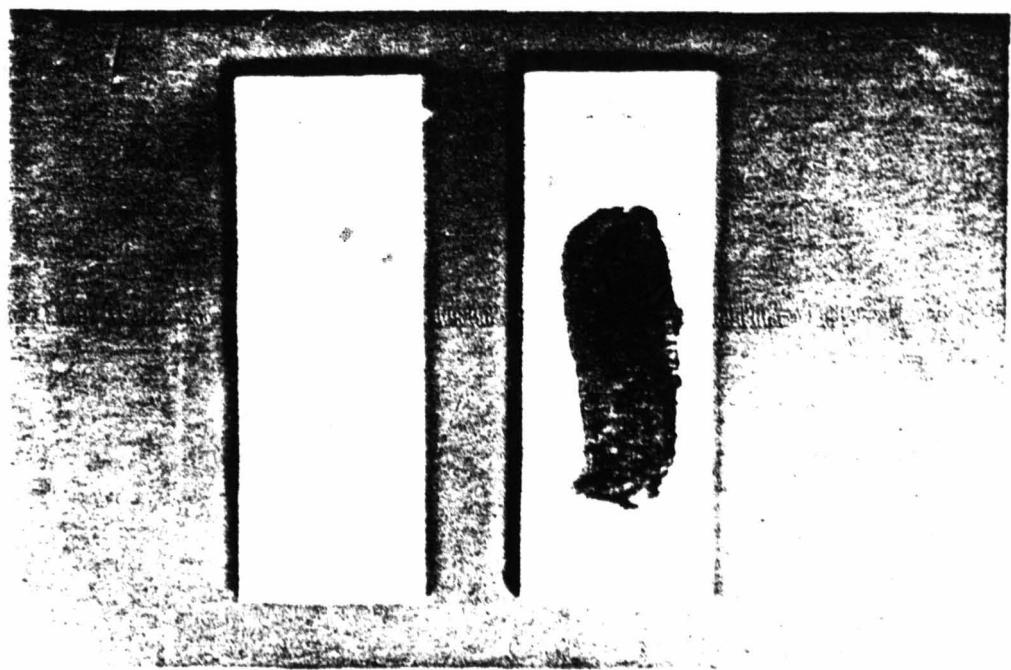
Both Glidflake and Hysol EA960F had good erosion resistance and both could be used to repair either Laminar X-500 and PR1654 coatings. The EA960F is easier to apply and can be smoothed out easier before it is set up.

The impact resistance of both Glidflake and EA960F was tested using a Gardner Impact Tester and the results compared to the impact resistance of the Laminar X-500 coating system. The impact resistance of the EA960F was equal to that of Laminar X-500 while the Glidflake was less impact resistant.

### 3.2.6 Conclusions and Recommendations

Based on erosion resistance, ease of application, and impact resistance, the EA960F structural adhesive was the best repair material tested.

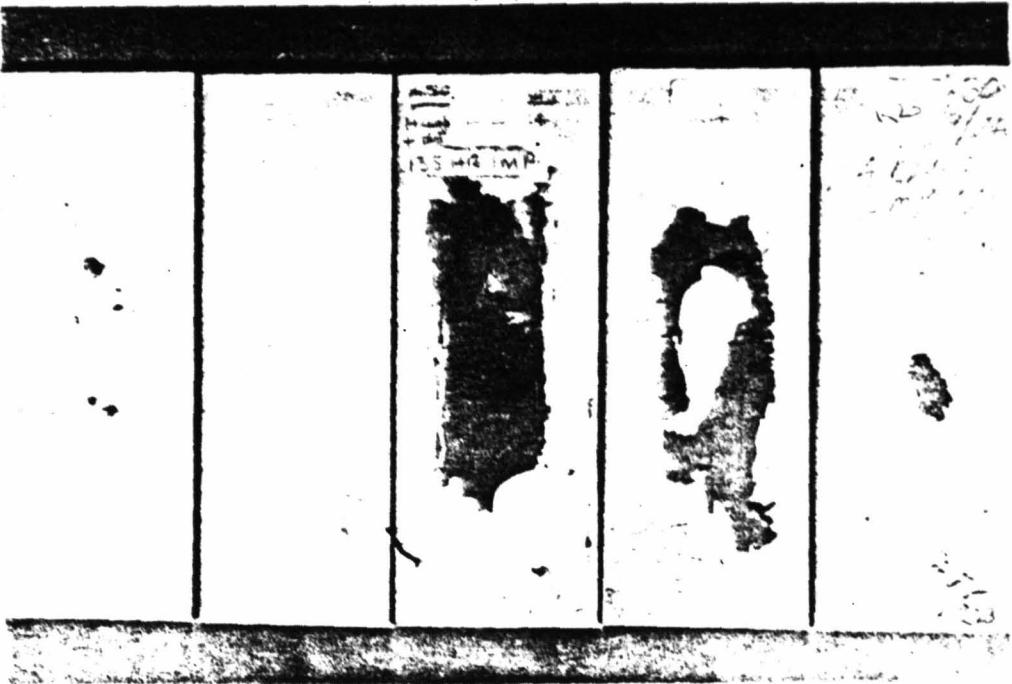
- a. Hysol EA960F should be used to repair both thin coating such as Laminar X-500 and thick coatings such as PR1654.
- b. When using EA960F in a one-hour emergency repair a minimum cure cycle of 30 minutes at 180 - 200°F is recommended.
- c. The minimum cure cycle for EA960F used for a 12 hour repair should be 8 hours at 70°F or above.



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Figure 19 TYPICAL REPAIR SPECIMENS AFTER EROSION TESTING

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Figure 20: TYPICAL REPAIR SPECIMENS AFTER EROSION TESTING

Table IX: SALTWATER EROSION AND/OR SPRAY TESTS OF REPAIR MATERIALS

REPAIR TYPE	SAMPLE NO.	WIRE METALLIZED		COATING SYSTEM TO BE REPAIRED	REPAIR MATERIAL	EXPOSURE TIME, HOURS		RESULTS OF TEST	
		Al	Zn			EROSION	SPLASH	BLISTERS	CORROSION UNDER BLISTERS
1 HOUR	R-1	NONE		1	BMS 6-102	92	0	NUMEROUS	BLISTER IN CENTER
1 HOUR	R-1A	V		2	BMS 6-102	229	144	SMALL BLISTER	
1 HOUR	R-2	NONE		2	HUGHSON 9924 PRIMER + PR 1653	136	0	BLISTERS AND PIN HOLES	CORROSION UNDER BLISTERS
1 HOUR	R-3	V		2	BMS 6-102	92	0	BLISTERS (BAD)	
1 HOUR	R-4	V		2	PR 1653 (NO PRIMER)	37	92	BLISTERS ALSO BLISTERS IN	LAMINAR X-500
1 HOUR	R-5	NONE		2	0.020" THICK PR 1654 PATCH MATERIAL AND CONTACT CEMENT	207	197	PATCH FELL OFF AFTER PANEL	WAS TAKEN OUT OF TEST
1 HOUR	R-6	V		2	HUGHSON 9924 PRIMER + PR 1653	48	288	3 SMALL BLISTERS	
1 HOUR	R-7	V		2	HY-SOL EA 960F	262	668	STILL GOOD	
1 HOUR	R-8	NONE		2	0.020" THICK PR 1654 PATCH & CONTACT CEMENT	117	48	ONE EDGE LIFTED, POOR ADHESION, AFTER REMOVAL FROM TEST PATCH COULD BE PULLED OFF EASILY	
									HUGHSON 9924 PRIMER + PR 1654 TOP COAT

1 LAMINAR X-500 COATING SYSTEM

2

Table IX: SALT WATER EROSION AND/OR SPRAY TESTS OF REPAIR MATERIALS (CONT'D)

REPAIR TYPE	SAMPLE NO.	WIRE METALLIZED		COATING SYSTEM TO BE REPAIRED	REPAIR MATERIAL	EXPOSURE TIME, HOURS	RESULTS OF TEST	
		Al	Zn				EROSION	SPLASH
1 HOUR	R-9	V		2	PR 1663 NO PRIMER	17	NOT FULLY CURED MATERIAL MOVED	
1 HOUR	R-10	V		2	PR 1663 NO PRIMER	17	NOT FULLY CURED MATERIAL MOVED	
1 HOUR	R-11	V		2	HYSOL EA 860F	26	ONE SMALL BLISTER SLIGHT CORROSION OF ALUMINUM UNDERNEATH, POOR ADHESION UNDER BLISTER	
1 HOUR	R-12	V		2	HYSOL EA 860F	307	BLISTER IN CENTER LOOKS LIKE STARTED FROM PIN HOLE	
1 HOUR	R-13	NONE		1	PR 1664 PATCH BONDED WITH BMS 6-102	166	FAILURE ALONG ONE EDGE APPEARS TO BE A TRANSITION BETWEEN PRIMER AND TOPCOAT WHERE FAIRING BY SANDING	
1 HOUR	R-14	NONE		1	PR 1664 PATCH BONDED WITH BMS 6-29 TYPE 2	NO TEST	PATCH BLISTERED AND MOVED ON CURING NO TEST	

1 LAMINAR X-500 COATING SYSTEM

2 HUGHSON 8824 PRIMER + PR 1664 TOP COAT

Table IX: SALT WATER EROSION AND/OR SPRAY TESTS OF REPAIR MATERIALS (CONT'D)

REPAIR TYPE	SAMPLE NO.	WIRE METALLIZED		COATING SYSTEM TO BE REPAIRED	REPAIR MATERIAL	EXPOSURE TIME, HOURS		RESULTS OF TEST	
		Al	Zn			EROSION	SPLASH	EROSION	SPLASH
12 HOUR	R-16	V		△	PR 1654 FILM BONDED WITH CONTACT CEMENT	184	0	FILM LOOSE AFTER 184 HOURS	
12 HOUR	R-16	V		△	HYSOL EA 860F	24	120	SMALL BLISTER IN CENTER	
12 HOUR	R-17	V	NONE	△	HYSOL EA 860F	348	300	STILL GOOD, NO DEFECTS	
12 HOUR	R-18	V		△	PRIMED WITH HUGHSON 9824 PRIMER, THEN OVERCOATED WITH 2 THICK COATS OF PR 1654 DIDN'T FILL DAMAGE AREA	216	12	IMPINGEMENT PATTERN ONE LARGE 1/4" DIA. BLISTER IN CENTER OF DAMAGED AREA	
1 HOUR	R-19		NONE	△	2 COATS OF 1B53 PRIMER ALLOWING 10 MIN BETWEEN COATS	170	64	SMALL BLISTER IN CENTER, RUST UNDERNEATH	
12 HOUR	R-20	V		△	1 COAT HUGHSON 9824 PRIMER, 1 COAT PR1654	24		BLISTERS IN COATING SMALL BUT NUMEROUS	

△ LAMINAR X-600 COATING SYSTEM

△ HUGHSON 9824 PRIMER + PR 1654 TOP COAT

Table IX: SALT WATER EROSION AND/OR SPRAY TEST OF REPAIR MATERIALS (CONT'D)

REPAIR TYPE	SAMPLE NO.	WIRE METALLIZED	COATING SYSTEM TO BE REPAIRED	REPAIR MATERIALS & PROCEDURE	EXPOSURE TIME, HOURS		RESULTS OF TEST	
					EROSION	SPLASH		
1 HOUR	R-21	NONE	AI	① HYSOL EPOXY PATCH 615 BLUE	16	0	MATERIAL ERODED AWAY	
1 HOUR	R-22	V	Zn	② SAME AS R-21	16	0	BLISTERED	
1 HOUR	R-23	NONE		① BMS 6-102	24	0	BLISTERED IN CENTER	
				② GLID FLAKE	256	120	STILL GOOD	
				③ GLID FLAKE	152	0	BLISTERS, ALSO BLISTERS IN THE OVERCOAT	
	R-24	NONE						
	R-25	V						

① LAMINAR X-500 COATING SYSTEM

② HUGHSON 9024 PRIMER + PR 1654 TOP COAT

Table IX: SALT WATER EROSION AND/OR SPRAY TESTS OF REPAIR MATERIALS (CONT'D)

REPAIR TYPE	SAMPLE NO.	WIRE METALLIZED		COATING SYSTEM TO BE REPAIRED	REPAIR MATERIAL	EXPOSURE TIME, HOURS		RESULTS OF TEST
		Al	Zn			EROSION	SPLASH	
1 HOUR	R-26	NONE		△	1863 PRIMER	232	8	STILL GOOD
12 HOUR	R-27	V		△	HUGHSON 8924 PRIMER + PR 1663	>120	0	FAILED MATERIAL ERODED AWAY
12 HOUR	R-28	NONE		△	SAME AS R-27	7	0	FAILED MATERIAL ERODED AWAY
12 HOUR	R-29	V		△	SAME AS R-27	>120	0	FAILED MATERIAL ERODED AWAY

① LAMINAR X-500 COATING SYSTEM

② HUGHSON 8924 PRIMER + PR 1664 TOP COAT

③ THESE SPECIMENS FAILED DURING A WEEKEND AND WERE NOT REMOVED UNTIL MONDAY

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- d. The repair area should be abrasively cleaned to obtain a bright metal surface and faired coating edge. A final cleaning with a solvent such as acetone or methyl-ethyl-ketone is recommended to remove all loose particles and contamination.

4.0 REFERENCES

1. D. D. Miller, "Hydrofoil Material Evaluation - Metals", to be published in 1974 as Boeing Document D180-15197-3.

## APPENDIX I

## Laminar X-500 Coating System Repair Procedures

1. Inspect damage area, remove loose dirt and coating material and degrease by solvent wiping with naptha or a similar solvent.
2. Using a rotary disc type power sander with 80 grit garnet or aluminum oxide paper remove all damaged coating down to a bright metal base. Fair the edges of the damaged coating to provide a smooth transition. Sandpaper smooth the faired edges by hand or with an orbital sander using 180 to 240 grit garnet or aluminum oxide paper. Wipe the area with clean rags and Methyl Ethyl Ketone (MEK) or acetone to remove any grit or abraded material.
3. Mix the Hysol EA960F adhesive 100 parts of Component A to 50 parts Component B by weight. Mix the material thoroughly using a spatula or putty knife. Component B is brown and Component A is white and when they are mixed thoroughly the entire material should turn red. This material has a pot life of 30 minutes at 70°F. CAUTION: Wear rubber gloves when handling to avoid skin sensitization or other allergic responses. Avoid inhalation of any vapor from the material and use good ventilation when mixing and heating.
4. After the material is thoroughly mixed, apply sufficient material to overfill the damage area.  
Remove the excess with a straight-edge or squeegee with one complete motion over the area. This step may be repeated several times to fill the damage area smoothly. Care taken at this time in applying and removing excess material will save sanding time after the material is cured.
5. Cure the material for at least 30 minutes at 180 - 200°F or at least 8 hours at a minimum of 70°F. Heat can be applied to the repair area using a portable hot

air blower (i.e. Model HG501L26 Heat Gun, Master Appliance Corp., Racine, Wisconsin).

6. After curing the repair area can be smoothed by using an orbital sander or hand sanding with 180 to 240 grit garnet or aluminum oxide sandpaper. Care must be taken not to sand the Laminar X-500 surrounding the repair area.

## APPENDIX II

### PR 1654 Coating System Repair Procedures

1. Inspect damage area, remove loose dirt and coating material and degrease by solvent wiping with naptha or a similar solvent.
2. Using a power rotary wire brush remove all damaged coating down to a bright metal base. Fair the coating at the edges of the damage area so that there is a smooth transition. Then using an orbital or hand sander with 180 to 240 grit garnet or aluminum oxide paper, smooth the faired edges. Wipe the area with clean rags and Methyl Ethyl Ketone (MEK) or Acetone to remove any grit or abraded material.
3. Mix the Hysol EA960F adhesive 100 parts of Component A to 50 parts Component B by weight. Mix the material thoroughly using a spatula or putty knife. Component B is brown and Component A is white and when they are mixed thoroughly the entire material should turn red. This material has a pot life of 30 minutes at 70°F. CAUTION: Wear rubber gloves when handling to avoid skin sensitization or other allergic responses. Avoid inhalation of any vapor from the material and use good ventilation when mixing and heating.
4. After the material is thoroughly mixed, apply sufficient material to overfill the damage area.

Remove the excess with a straight-edge or squeegee with one complete motion over the area. This step may be repeated several times to fill the damage area smoothly. Care taken at this time in applying and removing excess material will save sanding time after the material is cured.

5. Cure the material for at least 30 minutes at 180 - 200°F or at least 8 hours at a minimum of 70°F. Heat can be applied to the repair area using a portable hot air blower (i.e. Model HG501L26 Heat Gun, Master Appliance Corp., Racine, Wisconsin).
6. After curing the repair area can be smoothed by using an orbital sander or hand sanding with 180 to 240 grit garnet or aluminum oxide sandpaper. Care must be taken not to sand the PR 1654 surrounding the repair area.

## APPENDIX III

## WIRE METALLIZING PROCESS

Wire metallizing is the process of melting a metal wire in a heat zone and then propelling it, in a molten state, onto a part surface to form a coating utilizing a special metallizing gun. In this gun, a metal wire is fed at a controlled rate through an oxygen-acetylene heat source. As it passes through the flame, it is melted and atomized into a fine spray by a blast of compressed air. This air blast also serves to propel the atomized metal towards the part surface where it builds up as a solid metal coating. Proper preparation of the part surface is essential for optimum bonding of the metallized deposit. Typically, cleaning procedures involve vapor degreasing or solvent cleaning to remove all contaminates followed by grit blasting with a coarse abrasive to produce a roughened, oxide free surface.

Industrial Applications

The wire metallizing process is used by Industry in such diverse applications as machine element rework, both rebuilding worn parts and salvaging improperly machined parts, hard facing of components to improve wear characteristics, and the metallizing of conductive contacts on electrical components. Wire metallized aluminum and zinc coatings have also been extensively used to anodically protect iron and steel structures from corrosion. Typical of the types of structures which have been coated for this purpose are ship hulls, bridges, large storage tanks and factory installations. These coatings have also been found to be an excellent base for organic type overcoatings because of their porosity. The Boeing Company is currently applying metallized aluminum coatings, on a production basis, to large structural fiber-glass aircraft parts.

Wire Metallizing Hydrofoil Struts

The feasibility of applying wire metallized aluminum and zinc coatings to hydrofoil struts has been demonstrated by the similar applications to which the process is utilized in Industry. Prior to the production metallizing of any struts some additional developmental studies will be required. These efforts would be oriented towards establishing optimum manufacturing procedures and process controls for coating application. Repair procedures which are suitable for use in both field and shipyard environments must also be established and corresponding safety requirements identified and documented.

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